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An Ecological Study of Colliery Waste and an
Evaluation of the Role of Earthworms in its Reclamation.

Submitted for Master of Philosophy, (Systems,) by

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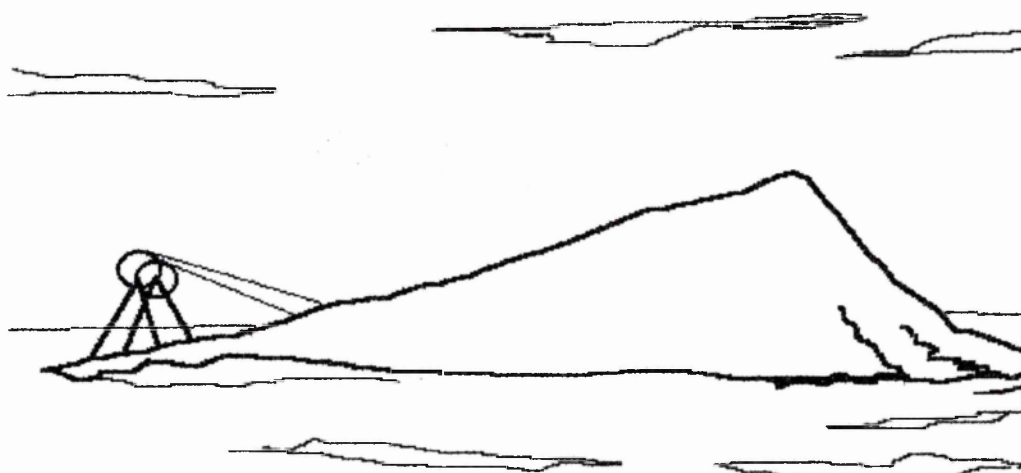
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**An Ecological Study of Colliery Waste and an
Evaluation of the Role of Earthworms
in its Reclamation.**



Frank Pearson.

*"Is it weakness of intellect, birdie?" I cried,
"Or a rather tough worm in your little inside?"
With a shake of his poor little head he replied,
"Oh willow, titwillow, titwillow!"*

The Mikado, Act II.

W.S. Gilbert & A.S. Sullivan.

Then t' worms 'll come an' ate thee up!

Ilkley Moor ba't 'at.

Old Yorkshire song, anon.



Plate I. Approaching the tip.

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Abstract.

A study of the earthworm populations of a naturalised deep mined coal spoil heap was undertaken. After an initial survey of the site, the history of the tip was researched to provide background for the present condition of the area. Documentary evidence, largely in the form of maps, suggested that tipping probably ceased in or shortly after 1920, and part of the tip was altered in 1960 due to roadworks.

The physical and chemical parameters of the incipient soil were examined, using standard MAFF soil testing methods, which showed that the tip contained some plant nutrients but was mainly clay and had a low pH over most of the area. By means of plant surveys over three years, the vegetation cover was shown to reflect the change in composition of the spoil over the site.

The worm populations present in the vegetated parts of the heap were in sharp contrast to their absence in the nearby bare areas which had a lower pH. The low pH was attributed to the acid produced by the oxidation of the pyrite present in the spoil. On the altered part of the tip, pH was neutral.

Methods of ameliorating the spoil from the bare parts of the tip were assessed through experiments using *Eisenia fetida* and various nutrients, both with and without lime addition. These experimental trials were undertaken in plastic cylinders, which afforded the opportunity of regular inspection and photographic records of the activities of the worms and their products.

Results, under laboratory conditions, indicate that it is possible to ameliorate both the texture and low pH of weathered colliery spoil, by the application of *Eisenia fetida* in vegetable matter.

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Finally, to my wife, for her patience.

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Chapter 1.

Introduction and Review of Literature.

1.1. The Setting.

The rapid closure of British coal mines following the 1984 miners' strike, has left many former coalfields, such as that in South Yorkshire, with a landscape littered with large tips adjoining the sites of former collieries. Some of these tips are already collecting a growth of naturally colonising vegetation, some not at all; and some of the older ones give the appearance, at a distance, of supporting healthy woodland. Hence the question has been asked, 'What is the purpose of reclaiming colliery spoil heaps?'

Formerly there was no legislation concerning repair of land after its use for tipping purposes. Today however, wider concern for the environment has resulted in legislation (HMSO 1994), which demands that land made derelict by mining or quarrying must be returned to its former state. The following definitions will form a basis for use in this work.

Derelict land is, '...land so damaged by surface or underground development that it is likely to remain out of use unless subjected to special treatment.' (HMSO 1956).

Reclamation is, '...the making of land fit for cultivation.' (Shorter Oxford Dictionary 1983).

Many parts of Britain still retain the scars of the coal mining industry and measures are being taken to remove them. Opencast coal contracts, which could increase in the future, include a clause concerning the return of the land to its former condition.

1.1.1. Methods used to reclaim colliery sites.

In Opencast mining the storage of topsoil, to be replaced after extraction, produces problems for organisms within the soil. High stacking and mechanical handling damages earthworms in the soil (Scullion 1988), but these problems can be overcome so that the system can work provided the original soils can be returned sympathetically. In the case of deep mines however large areas of land, almost 22,000 hectares in England (Richards *et al* 1996,) are buried under spoil, mainly shales. Formerly these tips were simply left so that after many years, weathering and regeneration took place leaving untidy areas of scrub. More recently attempts have been made to give the land a more pleasant appearance by regrading the landform and through cultivation.

Lister (1987), found that colliery spoil, being a poor growth medium, required the addition of high rates of fertiliser for plant growth however, and reclamation was more successful but more expensive using soil cover. The original soil had not been saved and therefore topsoil has to be found and imported to cover the spoil. Plants, especially grasses will bind the surface to prevent erosion and these are often planted in topsoil spread on the top of the shales. Lister further stated that there is no true bond between the topsoil and the spoil, it is also an expensive operation to carry out. He suggested that the nature of the spoil should first be considered, as the soil does not completely remove the plant from the spoil.

The topsoil is usually treated with fertiliser then seeded with a grass mix and may be used for cattle or sheep grazing (as at Brodsworth, the tip considered in this study), sometimes tips have even been used for arable farming (as at the site of the former Bulcroft Colliery, GR SE528102). The condition of many such coal tips which have been topsoiled cannot be described as sustainable. In addition to the expense, the soil may not be very stable on the spoil leading to erosion. Close examination shows deep gullies caused by water erosion, as the soil fails even on

modest slopes (see **Plate II, Page 4**). Deeply rooted trees may stabilise the topsoil and parent rock, ie broken and compacted shales and mudstones.

But what former condition is to be aimed for? The question of standards was discussed at length at the winter conference of The British Land Reclamation Society (REGRO), in December 1995 at Luton University. Whatever else may be debated, the condition of any resulting soil must be fit for its intended use, and it must be able to be sustained. While this study does not specify an intended end use for a particular derelict site, the vegetation which will ultimately grow on any reclaimed land will need a soil suitable for its needs.

At present, because of increased productivity in European farming, there is no pressure to produce agricultural land from spoil heaps. Current government policy leads to valuable land being temporarily 'set aside'. However, land for recreation or simply naturalising, is in demand, as well as land requirements for housing and industrial units. Reclaimed colliery spoil heaps will provide sites for fulfilling many of these needs.

1.1.2. Soil Formation.

Soil formation depends on the nature of the parent rock, its physical formation, its mineral composition, the type of weathering, climatic factors such as precipitation, and the biological forces of plants and animals.

Until weathering has taken place, only mosses and lichens are able to grow on rocks. As rocks are broken into smaller pieces, then seeds of pioneer vascular plants carried by the wind are able to germinate in moist pockets and roots penetrate between the particles. These pioneer plants trap dust to add to the mineral part, and as the plants die and decompose, form the organic fraction of a new soil. Over time, more plants will become established, grasses and herbs,



**Plate II. Erosion at the edge of the sheep field at Brodsworth Tip,
OS SE 525076.**

followed by a succession of shrubs and trees. Leaf litter from these plants will form a decomposing layer on the soil adding fibre and nutrients. Fungal spores will also be blown on to the surface of the soil and some will grow, as will soil microorganisms. Larger soil fauna will migrate towards the new soil as food sources are formed from plant material.

Davis *et al* (1992), suggested that the soil in Britain results from 10-14,000 years of post glacial time, during which climate, landform and biological influences, including man have all played a part. At the other end of the scale, sand dunes in Norfolk were reported to have developed 2cm of mull humus after 15 years with grass (*op cit*). In the long term, it may be possible to produce brown forest soils, the soil formed under deciduous forest, *in situ*, without importing topsoil. This sounds idealistic but a mixed woodland is considered to be the natural climax vegetation in Britain (eg Mitchell and Wilkinson, 1991), and the shales of the tips are unweathered rock. Should the need arise in future for agricultural land then the availability of gently sloping hills of brown forest soil would be valuable for conversion to either pasture or arable land.

1.1.3. Soil formation from Colliery Spoil.

All natural soils are formed from rocks which have been weathered, and colliery spoil is a mass of exposed rock. Initially all soils were inhospitable rock substrate, and colliery spoil is capable of weathering to a soil capable of supporting an ecosystem.

Davis *et al* (1992), list the factors which produce a soil as:

Climate,

Parent material,

Landform (relief and physiography),

Biological factors - plant, animal, man,

And time, although several factors operate simultaneously, and their importance varies in different situations.

It is hoped that the timespan to achieve a workable soil might be reduced considerably by managing the production of soil from rock by influencing natural agents, eg earthworms, to become more efficient. The importance of earthworms in soil formation processes has been recognised for many years. When studying the relationship between colliery waste particle size and plant growth, Down (1975), found no macrophytes on spoil less than 12 years old.

1.1.4. Pyrite.

Progress towards the establishment of a biological community in the shale may be hampered by the presence of iron pyrite, FeS_2 . Pyrite oxidises on exposure to water and atmospheric oxygen and may reduce the pH to 1.5 or 2.0.



Thiobacillus ferrooxidans is necessary for this action to take place but it may take well over a century to displace all the H_2SO_4 . Lime (Ca CO_3), Ankerite ($\text{Ca}(\text{Mg,Fe}) (\text{CO}_3)_2$), and Siderite (Fe CO_3), can all help to neutralise the acid.

However soil on which constructional work is anticipated should not be treated with lime. Pyritic spoil can heave due to the formation of gypsum (calcium sulphate), when sulphuric acid, formed during pyrite oxidation, reacts with lime containing minerals. Such heave has been most often documented in relation to the use of pyritic shales as fill or where construction has taken place on pyritic shales in situ (Richards *et al* ,1993).

1.1.5. Litter fall.

The rate of litter fall from vegetation will influence the rate of growth of decomposer organisms, including earthworms on any piece of land and so will

influence soil formation. Colliery spoil heaps are no exception to this generalisation. The annual litter fall in a *Betula* wood at an altitude of 180m has been recorded as 1.88t/ha (Mork, 1942). It is not surprising that climate can have a marked influence on litter production and production levels can vary from year to year. Soil conditions might have little influence on the amount of litter produced, as both mull and mor soils produce similar amounts of litter from *Fagus sylvatica* (beech). It is noted however that conifers show a threefold difference in litter production between poor and fertile soils (Phillipson *et al*, 1975).

The age of the trees is important as the amount of litter produced increases until the canopy is completed. The litter input to the nutrient pool at some of the older colliery tips can be considered to be nearing its maximum. On some the *Betula* cover is complete, and *Quercus robur* (the common oak) has begun to grow.

1.1.6. Other Influences.

No change is anticipated in the amount of litter from the herb layer on older tips, but a more rapid turnover of litter might be affected by the increase in *Oryctolagus cuniculus*, (rabbit) population. Rabbits have increased generally and some tips are becoming populated by them. Evidence of droppings on, and of trial burrows in, the spoil can be seen. This certainly ties in with the increase in rabbit population as the British population recovers from the myxomatosis epidemic of 1953 (Corbett and Southern, 1977).

Herbivores are an important part of the process of litter breakdown. Large quantities of vegetation are eaten and in the process are comminuted increasing the surface area / mass ratio. However only a small proportion of the vegetable matter is digested and the increased surface area of these pieces in the faeces provides more opportunity for colonisation by fungi and bacteria.

Rabbit faeces have been studied (Harper and Webster, 1964), and the fungi involved in the breakdown follow a regular cycle. In turn, sugars which are present in the partly digested faeces are consumed by Phycomycetes like *Mucor hiemalis* and *Pilaira anomala*. After six or seven days Discomycetes like *Ascobolus stictoides* and *Saccobolus violascens* begin to take over being able to work on the cellulose which the Phycomycetes are unable to do. Later on in the decomposition, Basidiomycetes such as *Coprinus sp.* appear and these are able to decompose lignin.

This process of returning nutrients from rabbit droppings to the soil will provide food for such species of worm as *Lumbricus rubellus*. These inhabit the organic horizon making horizontal burrows, behaving as épigés or endogés. A soil enriched by rabbit droppings partly broken down as described above may provide nourishment for *Lumbricus rubellus* as it eats its way through making its burrows.

By pulling leaves into their burrows, deep burrowing species of earthworm, such as *Lumbricus terrestris* and *Aporrectodea longa*, accelerate the rate of decomposition, as the burrows are damper than the dry surface. Also earthworm casts contain many more bacteria the surrounding soil (Mason, 1976).

1.1.7 Organic materials.

Humic acid, one of the products of plant decomposition, containing 56% Carbon, 5% Hydrogen, 5% Nitrogen, 34% Oxygen, as well as iron, silicon, aluminium, phosphorus, and other elements in small proportions reflects the composition of lignin in its synthesised compounds. These compounds in humus or humic acid become oxidised to a form suitable for plant nutrition (Jacks, 1958).

Pioneer plants first become established on the spoil heap before the arrival of worms. When plants are present, providing nutrients, worms can start the process

of mixing, draining and aerating the substrate. With the addition of humus from digested plant remains, the process of soil formation will begin.

It is time which man has difficulty in appreciating as the scale is normally so long. In order to reduce the time taken spoil is graded to reduce slopes and covered with topsoil. The process of grading has an effect of crushing the pieces of rock which is akin to weathering. Scullion (1994) compared the forces to which soils are subjected by machinery when replaced on opencast sites. His figures are relevant here as spoils at deep mined coal pits have been repeatedly crushed by heavy machinery. Some modern earthmoving equipment generates static ground pressures up to 800 kPa. Other comparable figures he quotes from various sources include grazing animals which produce a static treading pressure ranging from 80 to 170 kPa (Lull, 1959), and 100 kPa from conventional agricultural machinery (Soane, 1982).

Richards *et al* (1993) when suggesting that existing vegetation could play a useful role within the reclamation objectives for the site, said that existing vegetation might require additional management works such as species enrichment, control of invasive weeds or the improvement of soil fertility, in order that the reclamation objectives are fulfilled.

Richards *et al* (*op cit*) go on to state:

"Where pH is low there will be no succession until the pH is ameliorated, and colonisation will be by those plants that can tolerate low pH only; where pH is not limiting colonisation will follow a successional pattern with species composition dominated by local species."

As vegetation covers the ground it acts as a protective blanket reducing the effect of wind and rain as well as the extremes of temperature to which the bare surface

was exposed. To reduce the erosion of tips caused by wind and rain, topsoiling and seeding with a grass mixture has often been carried out.

When tips are topsoiled and seeded then the events described above are eliminated and the time between tipping and 'greening' reduced. However the boundary between spoil and soil is prone to separation by erosion, and the binding of the two by roots difficult to achieve. Trees if planted, will have limited root depth and when subjected to gales could lose anchorage.

Scullion (1994), points out that tillage operations, when seeding with grass, did not lead to permanent improvement in loosened soil. After six weeks, following seeding at Glyn Glas, (an open cast coal mine in Wales,) compaction had returned associated with soil slumping in the tillage layer.

Carbon from plant litter may quickly be lost as CO₂, or it may become incorporated into the biomass of decomposers decomposing the litter. A third fraction however may be protected from decomposition, either physically or chemically. The physically protected carbon is not well understood, but the chemically protected carbon is in the form of humus. Killham (1994) suggests that phenolic, lignin degradation products and some of the other products of residue decomposition are considerably modified by microbial reaction to form humic and fulvic acids, and humin. (Killham op cit.) These carbon products may take thousands of years before being oxidised to CO₂. Observations of worms in sand and colliery spoil under controlled conditions indicate that *lumbricidae* have the ability to add humus to these substrates altering their texture. (See **Chapter 7, Page 98**).

The suggestion that earthworms could alleviate this problem is worth following up. The compaction of soils is exacerbated due to fine particles filling the spaces between larger soil particles inhibiting the passage of air, water and roots.

1.2. Earthworms as viewed by Gilbert White and Charles Darwin.

In a letter from Selbourne on May 20th 1777, Gilbert White described the attitude of gardeners and farmers to earthworms. Both detested worms, gardeners because their work was made unsightly by them, and farmers because they believed that worms ate their crops.

White realised that the belief in worms eating seedlings was due to a lack of accurate observation. The creatures concerned, which were mistaken for earthworms, were the larvae of insects and small slugs. Instead of accepting this version of the niche occupied by worms, White, as a result of careful observation, wrote:

"... worms seem to be the great promoters of vegetation, which would proceed but lamely without them, by boring, perforating and loosening the soil, and rendering it pervious to rains and the fibres of plants, by drawing straws and stalks of leaves and twigs into it; and, most of all, by throwing up such infinite numbers of lumps of earth called worm casts, which being their excrement, is a fine manure for grain and grass." (White, 1788).

He then goes on to suggest that someone should write , *"A good monography of worms,"* in order that people would be better informed. This task was not carried out until Darwin, towards the end of his life, in 1881, produced, *"The formation of Vegetable Mould through the Action of Worms."*

This enlightened volume however did not acknowledge White's observations despite Darwin's familiarity with the work at Selbourne. Darwin took simple observations much further when he sought to discover the senses of worms, and their ability to judge the shapes of leaves to their own advantage when drawing them into their burrows.

1.2.1. Earthworm Ecology.

Wallwork (1983), notes that according to Bouché (1977), earthworms are divided into three ecological groups depending upon the level of soil they inhabit. They are:

Épigés - Litter dwellers usually between 10 - 30 mm long they are of uniform colour and include *Lumbricus rubellus*, *Lumbricus castaneus* and *Eisenia fetida*.

Endogés - these live in the organo /mineral layer forming horizontal tunnels and can be small or large. Endoges are weakly pigmented and include *Aporrectodea caliginosa*, *Aporrectodea rosea* and *Octolasion cyaneum*.

Anéciques - are the deep vertical burrowers which sometimes cast at the surface and collect organic material at night to draw down into their burrows. They are the larger species between 200 - 1000mm in length and are strongly pigmented. The common *Lumbricus terrestris* and *Aporrectodea longa* are typical of this group.

A well established garden with a mixture of soil uses can provide examples of each group. A colliery spoil heap however will provide limited environments depending on age.

Gardiner (1972), notes that :

"Earthworms can also detect degrees of soil acidity and differ in their tolerance of it...Allolobophora longa (sic) will not burrow into soil below pH 4.5, Lumbricus terrestris will not enter soil below pH 4.1 but Lumbricus rubellus will enter an acidity as low as pH 3.8...Their tactile and chemosensitivities direct them away from hard, very acid soils where there is little or no food, and tend to keep in soils that are loose in texture and rich in nutriment...Eisenia foetida

(sic) congregate in compost heaps and will move from sand to humus and sand, the presence detected by odours."

In Britain, *Eisenia fetida*, commonly called the 'Brandling worm', has been a favourite among anglers. More recently, *Eisenia fetida* has become popular (under its American name the 'Tiger worm'), among environmentally conscious gardeners as a maker of garden compost. The method is to place a colony of *Eisenia fetida* in a plastic container the size of a dustbin (with drain holes,) with a little soil and a layer of vegetable matter. The layer of vegetable matter has kitchen waste added occasionally, and the worms consume the vegetable waste turning it into a compost referred to as "vermicompost" (Applehof, 1981). The compost is a useful addition to garden soil as a provider of humus. The fluid output can be diluted and used as a liquid fertiliser.

The optimum temperature range for *Eisenia fetida* is between 15°C and 25°C. (Edwards, 1988). Below 10°C the worm stops processing waste, while below freezing or above 30°C it dies. While *Eisenia fetida* favours the warm conditions of decomposing vegetable matter *Lumbricus terrestris* and *Aporrectodea longa* for example, prefer the cooler conditions of their deep burrows.

These contrasting lifestyles fit *Eisenia fetida* and *Lumbricus terrestris* into contrasting niches as regards selection. MacArthur and Wilson (1967), described animals according to the ecological niche they occupy. 'r' selected animals are found in patchy, heterogeneous, and unpredictable environments where populations undergo erratic changes in size as opportunists. As a consequence, 'r' selected animals have a high reproduction rate, produce more offspring, they have a small body size and reach maturity rapidly. 'K' selection occurs where physical environments are more stable.

Pianka (1970), would suggest that épigés are subject to 'r' selection, and are pioneer species as they occur in unpredictable environments in the litter layer, are small and have a rapid rate of replacement. In contrast anéciques are subject to 'K' selection, being larger with a slower rate of replacement, and inhabiting a more predictable and stable environment in the deeper layers of the soil. Satchell (1980), divided the common lumbricids into, a) red pigmented surface living species which occur predominantly in habitats with organic surface horizons, and b) those without red pigment which live in mineral soils and occupy all agricultural habitats except compost. In all other respects, such as rate of maturing and reproduction, the two groups conformed with the 'r' and 'K' classification.

Timescales for soil formation vary widely from 10-14,000 years post glacial for British soil to 15 years on Norfolk sand dunes (Davis *et al*, 1992). Colliery spoil can take 40-100+ years to develop a soil structure (Hall, 1957). In studying the worms which have been found on colliery spoil, it is hoped to learn more about the process of turning sterile rock into viable soil. Since Darwin was the first to examine the formation of humus by earthworms, he would have been interested to examine the way in which worms might reclaim spoil just as in his work he studied the burying of ancient buildings by the production of worm casts. (Darwin, 1881).

1.2.2. Earthworms and Humus.

The value of earthworms in colliery spoil is that by composting plant remains they

"...perform the worm's function so essential in grassland of humifying plant residues and mixing them evenly with the soil." (Jacks, 1958).

By adding humus to the clay minerals of weathered shale earthworms form a clay/humus complex, which improves the texture of soil, and so improving drainage and aeration.

The ability of earthworms to participate, to any significant extent, in the formation of humus must be called into question according to Wallwork (1983), as ligninase has not been demonstrated in earthworms. Although the absence of ligninase in the earthworm gut limits the breakdown of plant tissue, the presence of cellulase in the intestines of some earthworms indicates an ability to break down cellulosic parts of plant tissue.

While fungi, particularly the Basidiomycetes, are able to break down woody tissue, (Killham, 1994), it is only thereafter that earthworms have an important role in the decomposition of softer tissue of less complicated structure as in the case of cellulose. This is demonstrated in the production of vermicompost where species such as *Eisenia fetida* produce a fibrous compost for humus-making in the soil together with a liquid plant nutrient.

Furthermore, the earthworm is itself affected by other factors, for example pH may have a limiting effect on worm distribution (Sims and Gerard, 1985), as does soil handling by man, or the presence of predators; while the establishment of vegetation gives worms a source of nourishment.

Extremely acid conditions will limit the amount of flora and fauna that will succeed on the spoil. In the absence of FeS_2 the shale has a pH of about 7 favouring a range of organisms, although as particle size has been shown to limit the growth of plants so the size of fresh shale lumps will inhibit earthworms until weathering has reduced particle size to a more workable one. Only small mineral pieces can be ingested to assist grinding food particles in the gizzard. (Wallwork, 1983). Earthworms may, according to species, tolerate various levels of acidity around neutral. *Eisenia fetida* would appear to accept a low pH with a habitat range of pH 4.3 - 7.5, *Lumbricus castaneus* 3.9 - 8.4. Both *Lumbricus rubellus* and *Octolasion cyaneum* will tolerate pH as low as 3.5. In contrast, *Lumbricus terrestris* and

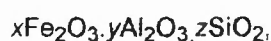
Aporrectodea longa will live in a minimum 6.2 and 6.7 respectively. (Sims and Gerard 1985, Killham 1994). (See **Fig 1. Page 17.**)

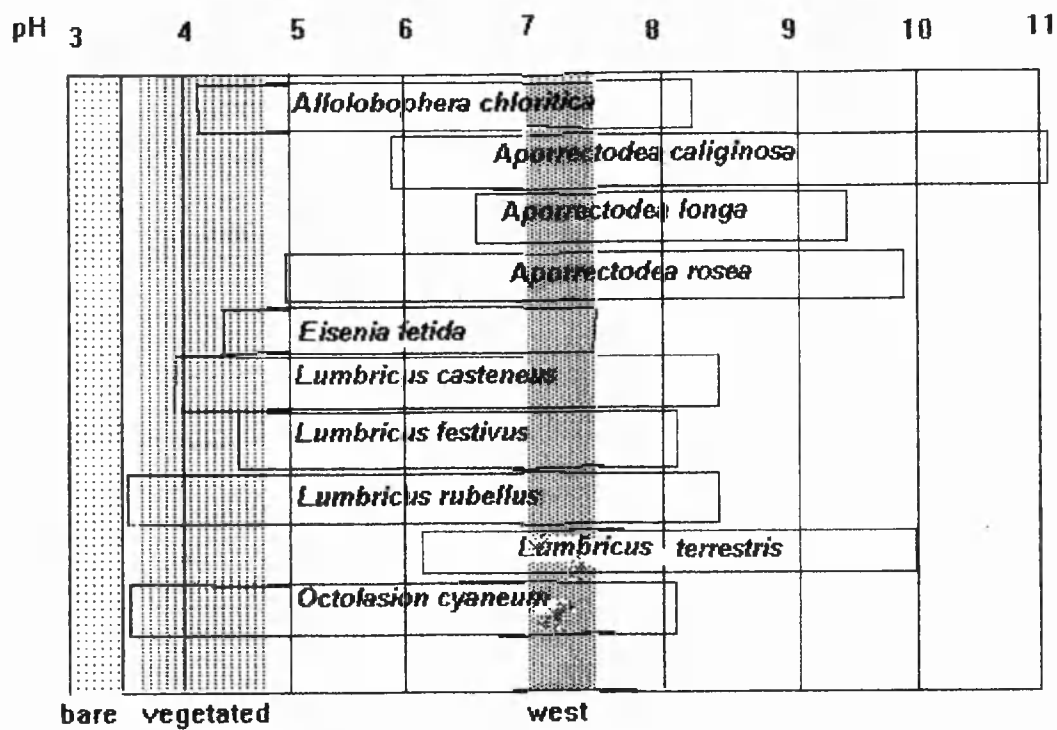
In contrast, Satchell (1955), suggested that *Lumbricus terrestris* and *Octolasion cyaneum* could both tolerate pH 3.7. (See **Fig 2. Page 17.**)

Although earthworms are only one of the many agents in soil development they are very important as shown by the results of their absence. Raw (1959), as noted in Davis *et al* (1992), examined the soil from an orchard from which the worms had been removed using a copper based spray, the soil lacked aeration and drainage, and the grass did not root deeply. The surface developed a peaty residue up to 4cm thick.

Similar results were reported from Holland where previously fertile soil quickly lost its porous healthy structure in the absence of worms, becoming cloddy, less stable and less porous (Davis *et al*, 1992). Again, observations were made by Lofty (1974), who further showed that the weight of leaf material buried in apple orchards is directly proportional to the weight of the worms present. The texture of heavy, lumpy, clay material from weathered colliery spoil has been shown to be altered to a lighter crumbly substrate after the action of worms under controlled conditions. (See **Plates XIX, XX, Pages 122 & 126.**)

Worms with their habit of ingesting a mixture of soil and plant residue are responsible for the potential formation of humus. Calcite (CaCO_3) produced by worms might add more ions to the complex. (**Chapter 7, Page 117** examines the calcite relations in further detail.) As noted earlier, worms will not invade a young spoil heap as the particles will be too large. The mineral part of our envisaged soil then will consist largely of weathered shale products. As shale is weathered to clay with a general formula of,

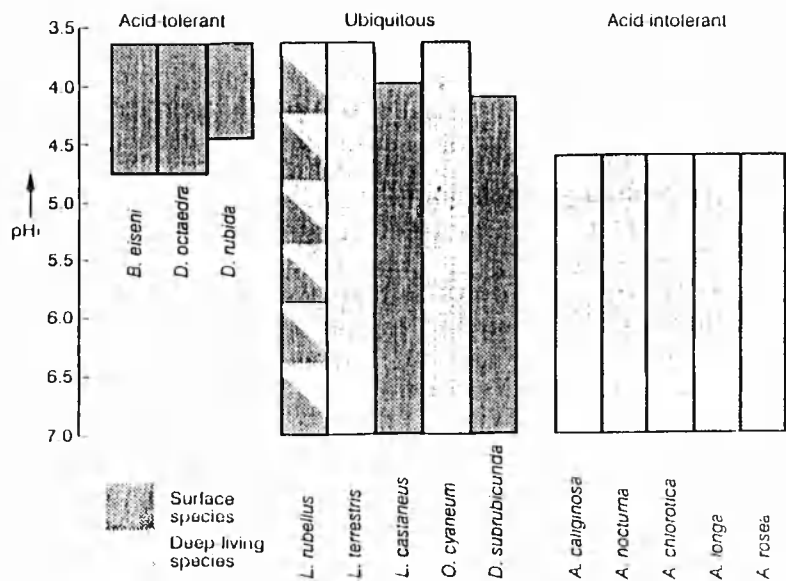




The pH of the habitats of some common worm species.

Shaded areas indicate the pH ranges on three parts of Brodsworth Tip.

Fig. 1. Worm tolerance of soil pH. (Sims & Gerard, 1985).



Classification of earthworms as a function of the pH of litter (after Satchell, 1955a).

Fig. 2. Worm tolerance of soil pH. (Satchell, 1955.).

it appears to offer no nutrients.

Scullion and Stewart (1988), showed that granulation of soil depended more on earthworms than on grass roots, when they wrote:

"When starting with a structurally degraded soil, grass acting alone, even in the presence of organic matter, can achieve no significant soil granulation but, given time, this can be achieved and sustained by growing grass in the presence of earthworms."

Further experiments carried out by Al-Bakri (1984) and Stewart *et al* (1988), showed clear evidence of an earthworm effect on soil structure development using, *Lumbricus terrestris*, *Aporrectodea longa* and *Allolobophora chlorotica*, on a silty clay loam.

It has been recognised for many years that earthworms make burrows by moving between large soil particles and ingesting small ones. The walls of these passages are held stable by a mixture of worm products, casts or sloughed cells from the worms' body wall. The resulting passages permit movement of air, water and roots. The mineral particles which have been ingested are voided as casts either within the burrows or on the surface depending on the species of worm (Wallwork, 1983).

The casts consist of fine mineral particles bound together by organic stabilising substances which form water stable soil crumbs. (Scullion, 1994). The formation of humus (which is the normal name given to these organic substances,) in soil is described by Killham (1994).

"Litter is primarily cellulose 50%, hemicelluloses 20%, and lignin 15%. When these are incorporated into the soil the following organic compounds predominate,

aromatics 50%, fatty acids and alkanes 15%, and carbohydrates 15%, with the remaining compounds all being N-associated." (Killham, *op cit*).

White (1987), noted that much of the soil organic matter adheres to the mineral particles particularly to the clay, to form a clay/humus complex. The complex is difficult to separate. Density flotation does not work, acetyl-acetone only partly dissolves the organic part, while sodium hydroxide depolymerises the organic compounds as it separates them from the mineral surface. The black solution resulting from sodium hydroxide treatment can be neutralised with HCl to pH2 which results in a humic acid precipitate and a fulvic acid solution. Even after such treatment, there is still a residue of humins adhering to the clay minerals which increases the water and nutrient absorption capacity of the soil. When soil fauna ingest clay with the humus then a colloidal clay-humus complex is formed. The clay-humus is the adhesive component of the water-stable crumbs. The complex may provide a faster turnover of soil nutrients, than either clay or humus alone, probably due to the humus oxidising more rapidly (White, *op cit*).

The ultimate products of the breakdown of organic compounds in the soil are carbon dioxide and water. Cellulose and hemicelluloses are depolymerised by enzymes resulting from microbial activity, and are oxidised to the simple compounds, and in the case of cellulose, energy as well.

'The guts of soil animals such as earthworms often have high levels of cellulase activity and can digest completely any partially decomposed plant material. In addition to this enzymic activity of the gut, the cellulolytic activity of gut microbes also contributes to the role of earthworms and other soil animals in cellulose decomposition.' (Killham *op cit*).

Killham (*op cit*) notes that worms have a mechanism for neutralising soil acidity, possessing calciferous glands on each side of the pharynx although it is often the effect of calcium deficiency rather than the direct effect of pH that precludes many soil animals from acid soils. In acid soils (below pH5), such as coniferous forest and moorland soils where acidity precludes the presence of earthworms, they are usually replaced by enchytraeid worms which have considerable acid tolerance. (Davis *et al.* 1992.)

It appears that there may be a useful role for earthworms in ameliorating colliery spoil, by draining, aerating and assisting in the formation of humus. This thesis examines this role in the context of one specific tip, at Brodsworth in South Yorkshire, (See **Fig 3. Page 21.**) and by the assessment of one type of earthworm, (*Eisenia fetida*).

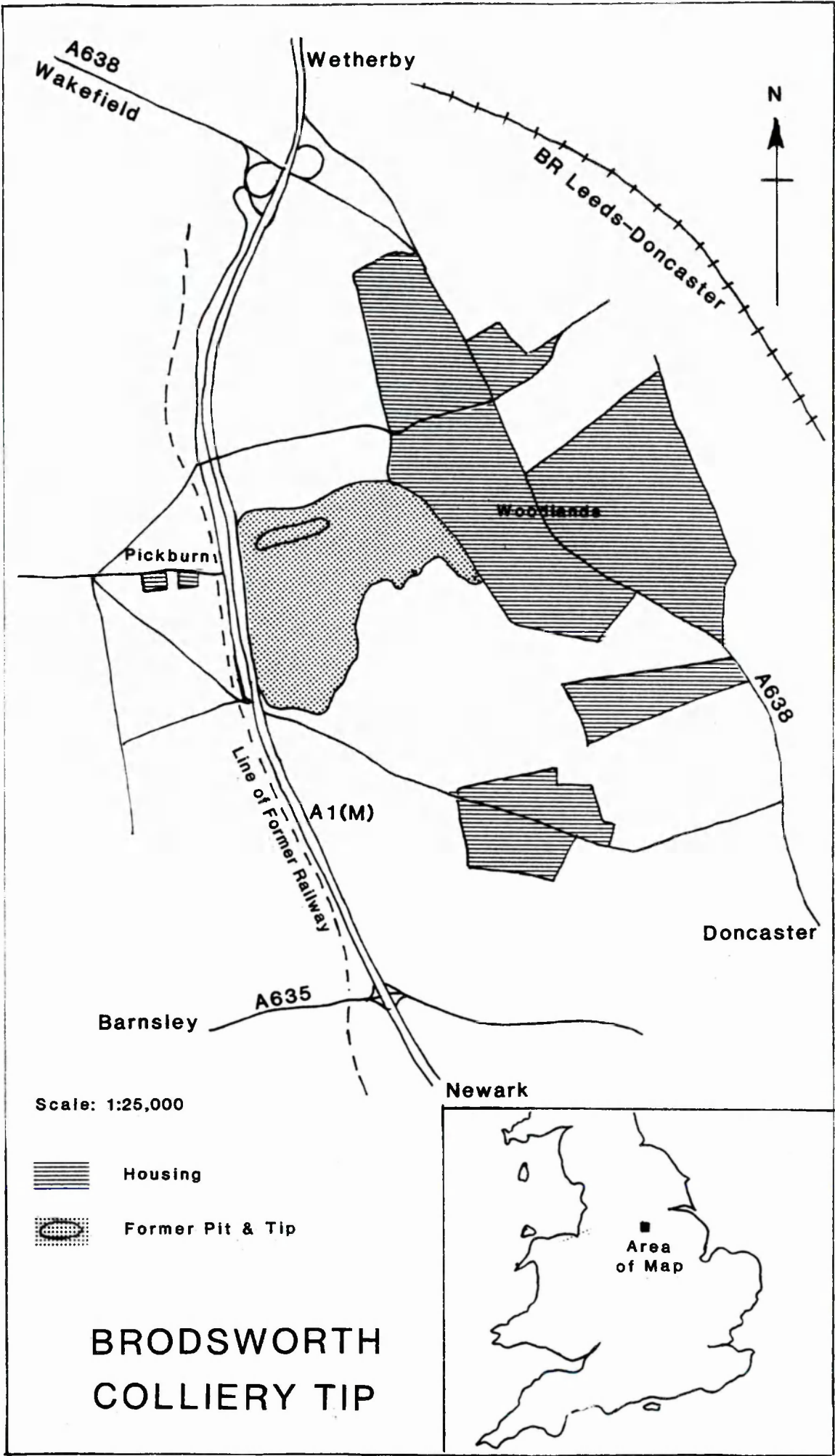
1.3. Summary.

Coal tips are generally considered to be unsightly, even though they do revegetate slowly. Revegetation is restricted by the slowness of soil formation, and soil formation is restricted by lack of vegetation. Earthworms are involved in the formation of soil; examination of the worms on Brodsworth Tip might help us to better understand the processes of soil formation on colliery spoil.

'It is through mixing and comminution of plant debris, rather than decomposition, that earthworms contribute most to ecosystem productivity' (Killham). He goes on to quote Lee (1985), who stated that earthworms rarely accounted for more than 5% of the energy flow through a decomposer system compared with 90% for the microbial biomass.

Reeve (1996), stated that:

"Many of the difficulties in achieving a beneficial end use of restored land are due to soil problems resulting from lack of attention to standards for soil



specification...there is a widespread ignorance of what makes good soil-forming material."

He summed up the answers to the problems of reclamation simply as:

"Get the soil right and the rest will follow."

1.4. Aims.

From the preceding discussion, the aims of the work described here were:

1. To establish the history of the case study tip. The site selected was the initial tip at Brodsworth Main Colliery in South Yorkshire, (GR SE522076). See **Fig 3.**

(Page 21.)

2. To investigate the characteristics of the above named colliery tip.

3. To examine soil formation in different parts of the tip.

4. To investigate the possibility of a relationships between soil, vegetation cover, and the earthworm population.

5. To investigate the potential for using worms to ameliorate the coal spoil under controlled conditions.

Chapter 2.

BRIEF HISTORY OF BRODSWORTH PIT.

2.1. The Tip.

Brodsworth is on the concealed coalfield which was developed around the turn of the century as the exposed coal in the Barnsley area became worked out.

Although the workforce rose to over three and a half thousand by 1955, and annual production regularly exceeded a million tons, the tip which is studied represents only the spoil from sinking the original shafts.

When the colliery was sunk in 1905, a large amount of rock had to be dug out before the Barnsley Seam was reached. Two shafts were required, each six metres in diameter (S.Thompson pers.com). The bottom of the Barnsley Seam was 592 yards or 541 metres from the surface (Wilcockson 1950). Thus the volume of rock to be removed and tipped can be determined as 30,000m³. The dimensions of the study area, which was the first tip at Brodsworth, are 250m x 25m, with a mean height of 5m, giving a volume of approx. 30,000m³. These figures suggest that the tip consists mainly of shaft material, with some shales and mudstones from the early years of production.

Tipping in the early days was not carried out with a view to later development, that is a very modern concept. Also over the years since official tipping of colliery spoil ceased, the land has been the recipient of various items of worn out equipment from the pit such as cables and belts. The removal of the railway line and sidings would have also contributed to further dumping.

Notable events from the maps and other sources included the following:

- A copy of the Inclosures of the Brodsworth Hall Estate dated 1805
(**Plate III, Page 24.**) shows a pattern of roads and fields which can be

SITE OF TIP





Plate III. Inclosure Map 1805.

- traced through subsequent maps, and the hamlet of Pigburn(sic).
Pickburn as it is known today is still there in a somewhat altered state.
The tip crosses parts of the sites of the plots numbered 173, (Underhills Close), 174, 175, and 176. See overlay.
- Work on sinking a pit at Brodsworth was begun in 1905 with the Barnsley Seam being reached in October 1907, '...earlier than expected...' (Jubilee 1955).
- The initial tip, (the subject of this work), was constructed by a tub system diverted from the rail to Pickburn Junction which linked the pit to the Barnsley and Hull Railway. The rail, as shown on the maps ran from east to west on the north side of the tip, swinging to the south to link up at the junction (see **Fig 4, Page 26**). The tip started at the east edge of plot 173 perhaps 100 metres north of the southern boundary, spreading to 100 metres wide north to south in a westerly direction. It crossed the plots 174 and 175, tapering to end in plot 176, giving an overall length approaching 400 metres.
- Tipping on the study site stopped before 1930, followed by the start of adjacent tips built by aerial bucket systems. The tip was left untouched until 1960 when construction of the A1(M) Doncaster Bypass was begun. The 1966 Ordnance Survey (see **Fig. 4, Page 26**), shows the A1(M) running parallel to the railway with the branch line crossing it via a bridge. There is no detail of the spoil heap however apart from a sludge bed on the diverted part of Underhills Drain.
- More recently the laying of a water pipe to the pumping station at GR SE521075 (OS 1980) on the south side of the tip necessitated the

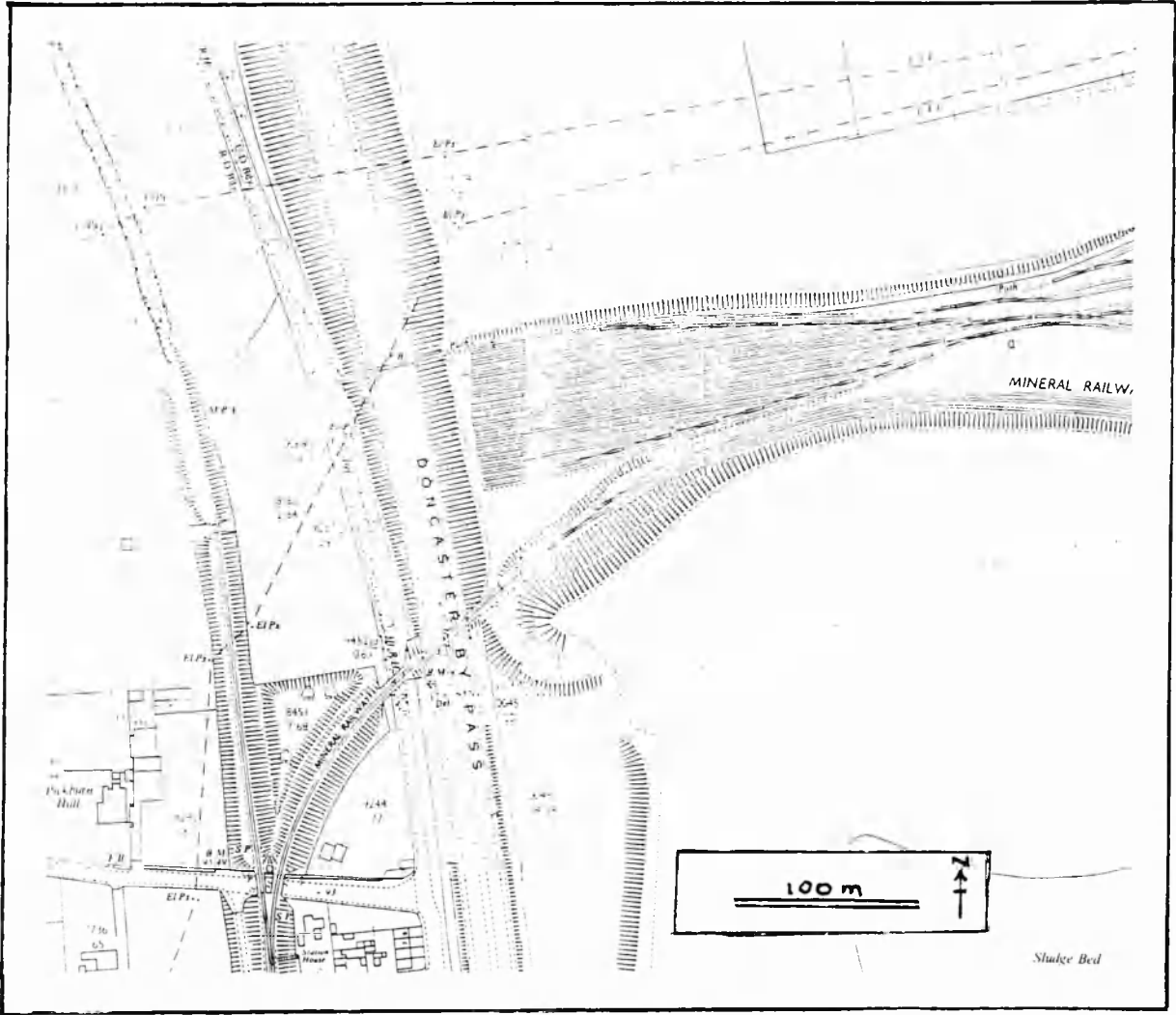


Fig. 4. OS map 1966.

Showing how the tip and rail were shortened by the motorway construction.

- removal of a long strip leaving an almost perpendicular face on the south side (see **Plate IV, Page 28**).

By combining the two historical maps with the 1989 revision of the British Coal map (see **Appendix 1, Page 136**), showing details of the structure of the tip today, it can be seen that at the time of the construction of the A1(M), the western end of the tip was removed to enable the motorway to pass. As part of the landscape enhancement the scarred tip was covered with soil. This would almost certainly have come from the line of the motorway built in 1960. The motorway at this point is some 800 metres north of a former Magnesian Limestone quarry and a similar distance from another in a west north westerly direction. Underhills Drain now flows through a pipe along its original route from a pumping house near the tip, (GR SE521075), separated from Pickburn by the motorway. (see **Plate V, Page 29**).

The drastic reduction in the size of the railway network following the Beeching Report of 1966, included the closure of the line through Pickburn. A rail link from the pit also existed in the opposite direction so the bridge over the motorway and the associated sidings were removed leaving a derelict site, now covered with scrub vegetation. The pit ceased production in 1985.

2.2. Sinking the Pit.

The Brodsworth Inclosure Award map of 1805 shows that a large part of the pit area was given over to Sheep Walks. Pigburn (Pickburn) had allotments, (fields whose leases were owned by various people and were worked by them,) around the hamlet. All the land appeared to be owned by the Thelluson family of Brodsworth Hall.

Thellusons in partnership with Markhams, an engineering company from Chesterfield, were responsible for sinking the mine in 1905. When Mr Thelluson



Plate IV. The south side of the tip, cut away to enable Underhills Drain to be piped.



Plate V. Foreground, the pipe carrying Underhills Drain.

Midground, the pool beside the pumphouse.

Background, grassed tip used for sheep.

dug the ceremonial first sod he insisted on filling a wheelbarrow which he subsequently trundled to a nearby field to empty (Jubilee 1955). Thus the original tip was begun.

(The wheelbarrow is preserved in Cusworth Hall Museum, Doncaster).

2.3. Doncaster Rural District Council Records.

In 1995, a search was made at the Doncaster Archives Office for evidence supporting the shortening of the tip at Brodsworth, and if possible evidence that the scar was covered with soil rich in Magnesian Limestone.

Plans were drawn up in 1957 under the Special Roads Act of 1949. Maps were drawn showing the centre line of the proposed motorway bypass which was to have two lanes in each direction. Several detailed maps of locations where the construction would affect other roads were also drawn, one of these was titled, 'Red House Lane (South) and other improvements' (see **Fig. 5, Page 31**).

This particular map shows the motorway, its embankments and altered roads drawn over the then existing system of roads around Pickburn. Unfortunately for the purposes of this work, the base map used probably dated from 1930, although showing roads accurately, it gives an illustration of the tip shape which was certainly out of date by 1956. However, the line of the proposed edge of the motorway cutting reduces both the amount of land occupied by the railway sidings and that of the tip. At least 50 metres were lost from the length of the rails in the siding. The amount of tip removed is less easy to ascertain, but the boundary of the colliery site followed Red House Lane at this point and the lane was fairly straight as is the motorway on this stretch. It can safely be deduced that the amount of tip removed was of a similar length.

A letter from the Highways and Bridges Department at the West Riding County

Approximate Shape of the Original Tip
(Broken Line)

Public Footpath

Path behind Motorway Fence

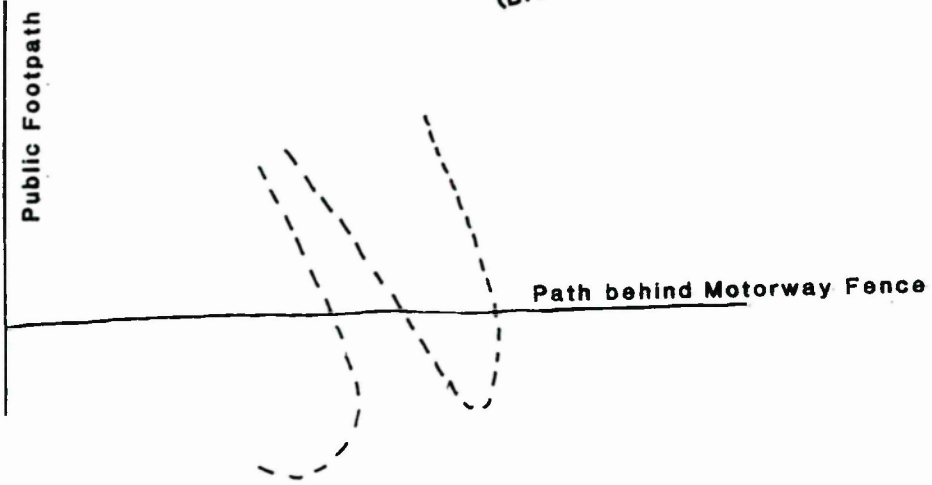
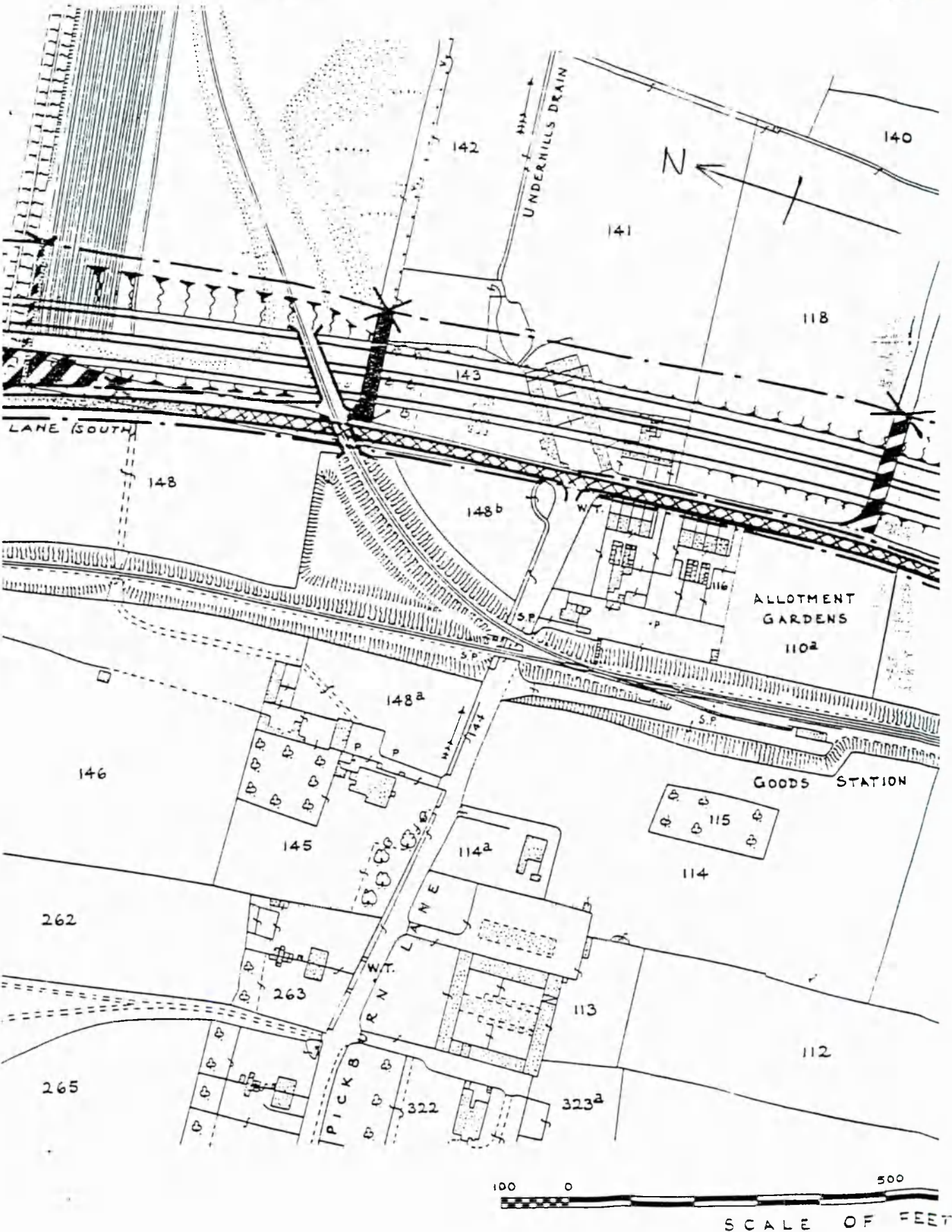


Fig. 5. Red House Lane improvement plan, 1957.

RED HOUSE LANE (SOUTH) AND OTHER M



Council at Wakefield, to the Doncaster Rural District Council, gave proposals referring to maps. Among others were:

No 63. Stopping up access roads between fields 118 and 109.

No 64. Regrading and realignment of Pickburn Lane.

No 65. Regrading and realignment of Red House Lane.

No 66. Stopping up access road south of Brodsworth Colliery Sidings.

No 67. Stopping up part of Red House Lane.

No 68. New road to replace above.

No 68a. Stopping up of footpath north of Brodsworth Colliery Sidings

No 69b. New footpath (including pedestrian footbridge) to replace above.

No 69. Regrading and realignment of Red House Road.

It is noticeable that no mention is made of the railway nor the railway bridge crossing the motorway. No mention is made of removing sidings and spoil heaps belonging to the Colliery. In other parts of these council records the only items of interest were those which concerned the Council directly, such as rehousing people who lived on the proposed route, care to be taken over a sewer which crossed the new road, or the erection of additional street lighting.

The contract for building the new road was awarded to Civil Engineers, Cubitts, Fitzpatrick and Shand. Work began in 1957 and the motorway was opened in 1961.

No reference was found concerning the landscaping of adjoining sites such as spoil heap at Brodsworth which was disturbed by the road building programme. While it appears plausible that local calcareous material was used in the restoration of the western end of the tip, no definite documentary evidence could be obtained from the sources located.

Chapter 3.

Description of the Site - Brodsworth Colliery Tip.

3.1. The Tip today.

The study area on the tip is a long mound covering about one hectare lying east to west. There is a gentle rise on the eastern end and a steep slope at the western end. The southern side is a sheer drop, cut away to accommodate a pipe carrying a diverted stream, and the north side gets steeper towards the west. To the north the land flattens on to the site of former railway sidings. The maximum height of the tip does not exceed 10 metres above the surrounding land.

Betula sp. (Birch woodland) covers most of the area except the western slope which is similar to the adjacent motorway cutting with a mixed herbage where *Crataegus monogyna* (Hawthorn) predominates (see **Plate VI. Page 34.**)

There is sparse vegetation (*Betula sp.*) to the north side on the site of the former sidings. To the east and south there is only bare shale, but beyond, later larger tips have been covered with soil, seeded with a grass ley mix, and sheep have been successfully grazed for some 20 years. By the side of the motorway cutting, *Crataegus monogyna* is so thick that it is difficult to discern the boundary fence between the British Coal and Highway properties.

Around the tip, on three sides there is agricultural land. On the fourth, to the east, there is housing. The village of Woodlands was built beside the pit to house miners. Hedgerows and verges will provide indicators of the natural habitat and routeways for migration.



Plate VI Change in vegetation at the west end of the tip.

A diagonal from the bottom right hand corner divides the picture. *Betula* is to the right and *Crataegus* to the left.

The area is on Magnesian Limestone as shown on the geological survey maps.

Old maps show the locations of several former quarries (see **Appendix I**).

Limestone walls are still common in the area bordering some fields and limestone is currently being extracted south of the tip at GR SE525076 by Tilcon.

After tipping ceased the topography of the site would be an important determinant of the plants which would succeed on the tip.

3.2. Ecology.

Because of its geographical position, South Yorkshire enjoys a climate relatively free of extremes. Freeze-thaw action is the most important weathering agent reducing shale particles down to clay size, becoming an argillaceous residue.

Periods of heavy rain will transport the finest particles in a slurry down the slopes.

Since the disaster at Aberfan, South Wales in 1966, the slopes at all pits have been modified to prevent large scale movement of slurry but erosion is still likely to occur on unprotected surfaces. At an altitude between 40 - 60 metres,

Brodsworth is not noticeably wetter than nearby Doncaster, which at an altitude of about 10 metres, had an mean annual rainfall of 52.2cms (20.5 inches), in the last four years of available data (HMSO 1990-1993). This is drier than the average annual rainfall of 71cms (28 inches) reported by Pearsall (1950).

The tip itself would drain quickly in dry weather, in the Doncaster area evaporation equals or exceeds precipitation for five months of the year (Pearsall 1950,) but on the lower parts as on the railway site, clay particles would be washed down enabling pools to form, providing wet environments for *Carex* sp. (Sedge) etc.

3.3. Spoil and vegetation.

One would expect to find calcicole species in the area but these would not survive on the tip. Chapter 5. **Page 73** shows that the succession at present

depends on *Betula pendula*, (Birch) which is acting as nurse to several *Quercus robur*, (Oak) saplings. These are most numerous at the eastern end of the tip. Lime from the railway ballast could raise the pH as it was spread around, which would provide conditions which has enabled *Ophrys apifera* (Bee Orchid,) to become established (see **Plate VI, Page 37**).

Without the addition of imported topsoil, Hall (1957), suggested it may take 40-50 years for a shale to resemble soil, but even after twice that time it may lack a proper soil structure. His profile (1957) of a 100 year old coal shale waste heap is quoted here:

Table i., Hall's profile of a coal shale waste tip.

depth (cm)	Profile description
0 - 8	Dark brown loam, large crumb structure, mully, spongy, very porous and friable .. occasional worms .. pH 4.8, fairly distinct from -
8 - 20	Brown loam, crumb structure deteriorating with depth .. well rooted, worms, merging into -
20 - 31	Grey silt loam, frequent large shale fragments and abundant small fragments, structureless .. merging into blue grey, scarcely weathered shale.

Parts of Brodsworth Tip (70 - 90 years old) can be recognised from the above description (see **Plate VI, Page 38** and Chapter 4, **Page 44**).



Plate VII. *Ophrys apifera* growing on Brodsworth Tip,
and on the site of the railway sidings.



Plate VIII. Profile of weathered spoil, Brodsworth.—

As the first tip at Brodsworth was built, it would have become compacted. Even without compaction by machinery, restored soils tend to compact due to water loss (Hunter and Currie 1956) leading to excessively high bulk densities and restricted root movement (Scullion and Mohammed 1991).

Like other South Yorkshire colliery tips, at Brodsworth pH is almost certainly limiting and needs amelioration if the vegetation is to be typical of the area. Such a proposition would mean an immense engineering project to change the whole tip from an acidic clayey shale to a soil rich in Magnesian Limestone.

Bradshaw and Chadwick (1980), have shown that species numbers on spoil heaps may correlate more closely with pH than with age. The low pH and the apparent low numbers of plant species found on most of the tip at Brodsworth accord with this finding. At this point it would be advantageous to find out what the rocks are which make up the tip.

3.4. Geology.

As the sinking of the mine proceeded, the succession of rocks removed was first 64 yards (58.3metres) of Permian Clays and Limestones before the Coal Measures Series. The series of cyclothems (the sequence of strata found above and below coal seams), follow the similar pattern of seat earth, coal, and shale, occasionally punctuated by sandstone bands (see **Figs 10 & 11. Pages 40, 41**).

When the Barnsley Seam was worked only the Hard Coal and the Bright Coal was extracted. The Top coal was left as a roof (S.Thompson Pers. com). The Branch was a poor quality Cannel Coal which would be left in situ unless problems of floor lifting (quite common), took place. Clod which was a soft mudstone might come away with the working. Both above the workings and below the Clunch (clays and mudstones), came shales. These are the original rocks which have produced the clayey spoil found on the first tip (see **Plate VIII. Page 38.**) The table showing the

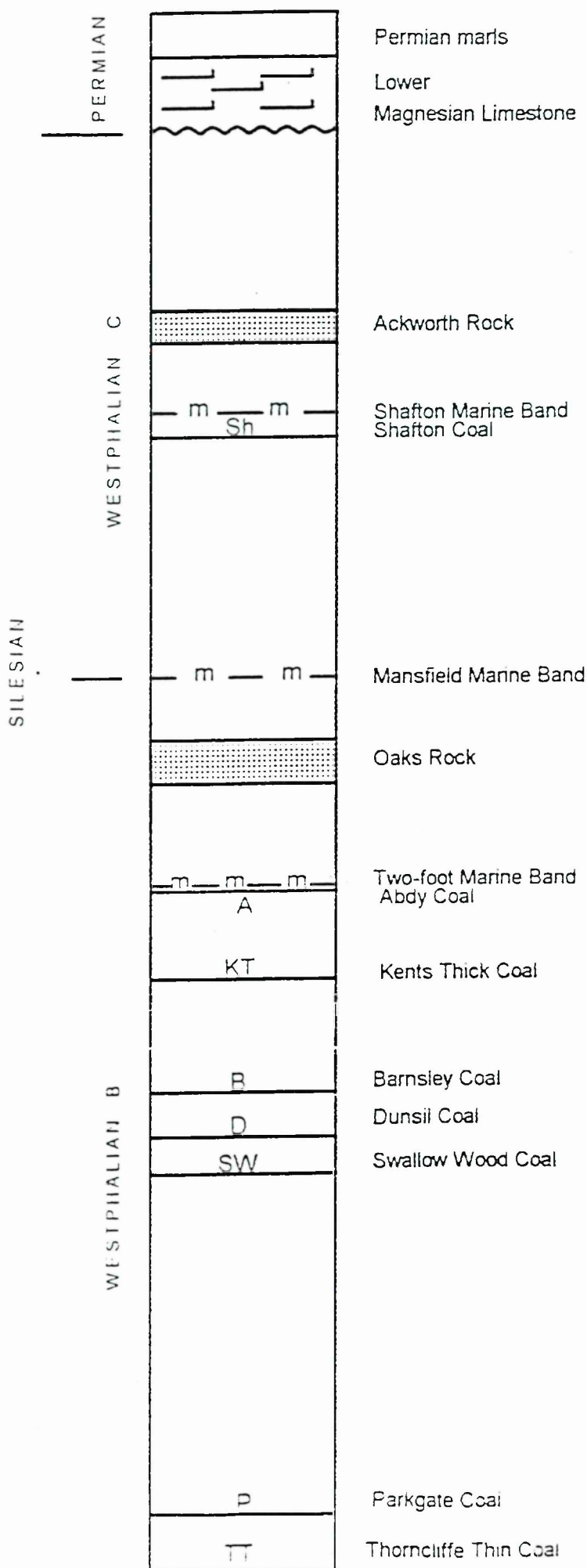


Fig. 6. After Spode based on Mitchell et al. (1947).

CYCLOTHEMS of the BARNESLEY BED.

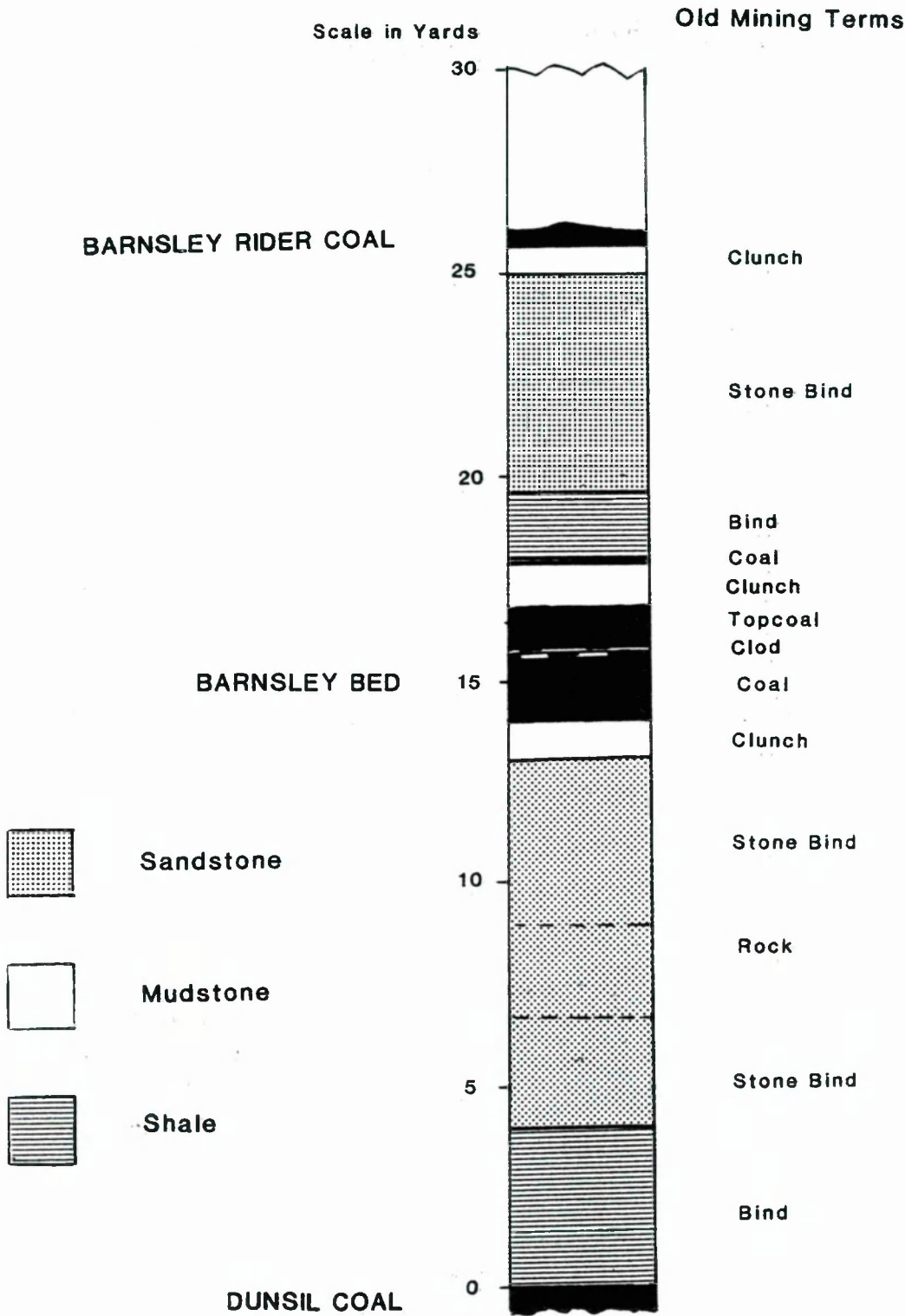


Fig. 7.

Based on Wilcockson(1950) *FP*

Table ii.

Glossary of mining terms.

APPENDIX III

GLOSSARY OF MINING AND QUARRYING TERMS USED IN THIS MEMOIR

Bag-muck	Dirt parting above the bags (<i>q.v.</i>).
Bags	Inferior coal associated with the upper part of the Barnsley Coal.
Bastard	False, e.g. Bastard cannel, bastard ganister.
Bat or bats	Highly carbonaceous, black shale.
Bind	Shale or imperfectly laminated mudstone; often applied by miners to any fine-grained rock.
Black list	A band composed of thin layers of bright coal and fusain in the hards of the Barnsley seam.
Blind shaft	A shaft sunk from a position in underground workings; sometimes called a staple pit.
Branch	Dull, hard coal forming the top part of the Silkstone seam.
Brasses, brassy	Iron pyrites.
Brazils	Pyritous coal.
Cank	Used generally for a hard, compact, fine-grained sandstone, silkstone or bind which is resistant to drilling. However, the cank associated with the Mansfield Marine Bed is a grey, even-grained, ankerite mudstone.
Clay seam	Inferior coal between the hards and top softs subdivisions of the Barnsley seam.
Clay seam dirt	A clay parting between the clay seam and the top softs subdivision of the Barnsley seam.
Clod	Soft and weak mudstone or shale traversed by oblique joints having slickensided surfaces.
Clunch	Clay or mudstone with rootlets.
Dandies	Impure coal forming top and bottom layers of the Parkgate seam.
Day-hole, day-eye	An adit or mine entrance.
Galliard	Local name for ganister (<i>q.v.</i>).
Ganister	Very fine and evenly grained siliceous rock with secondary silicification, containing casts and impressions of rootlets. Its fracture is subconchoidal. Almost invariably forms part of the seat of a coal seam.
Holing clod	Bed of clod in which shot-holes are drilled.
Lift.	A term much used in quarrying to denote a single bed of stone whose thickness is determined by the distance between one bedding-plane and the next.
Reddle	Decomposed, red, earthy haematite.
Slotting coal	The lowest subdivision of the Barnsley seam and that in which undercutting is done during the process of mining the seam.
Smut	Weathered coal, usually at outcrop; or coal and dirt. A thin smut is often the only evidence of the former existence of a coal seam.
Spavin	Earthy clay with rootlets.
Stone bind	Silty or sandy mudstone or shale; sometimes used of a fine-grained flaggy siltstone.
Stone coal	Coal with much argillaceous impurity, approaching a carbonaceous shale.
Swilly, swilley	A local thickening of a sedimentary deposit; more often applied to beds of economic value, e.g. coal, fireclay, etc.
Tender bind	Soft shale or mudstone.
Vugh	Small cavity in rock, usually lined with crystals.

WILCOCKSON (1950).

Glossary of Mining and Quarrying Terms taken from the "Geology of the Country around Barnsley," (Wilcockson 1950) is useful when studying the sections (see **Table ii. Page 42**).

Simply leaving colliery spoil heaps such as Brodsworth to naturalise completely with no treatment whatsoever appears to take too long. It may be possible however to shorten the time through the action of earthworms. The shales need to be weathered and compaction by heavy machinery hastens the weathering process resulting in the formation of clay particles. However, compacted soils, especially clays, are difficult for roots to penetrate. If worms can be encouraged to work the clay, then the texture may be altered from a glutinous mass to a crumbly soil.

3.5. Vegetation change.

The change of vegetation at the end of the tip (**Plate VI, Page 34**), prompted enquiries about the history of tipping at Brodsworth. British Coal Mining records office at Burton on Trent were unable to assist as "*...no legal requirement prior to 1971 for collieries to record tipping activities...*", (Pers.com.) was required.

However, a search for copies of old maps in the area was initiated and a sequence of events was traced to describe the history of the tip. Once the history of the tip had been established, it was then important to examine the nature of the developing soil.

Chapter 4.

4.1. Soil Studies on the tip.

An examination of the spoil at Brodsworth was necessary, so three areas were selected for detailed examination (see **Fig. 8, Page 45**).

- a) The wooded part on top of the tip which supports a strong growth of *Betula pendula* (Birch).
- b) A bare patch within the wooded area which has some mosses,
- c) The slope at the end of the tip near the motorway, which supports *Crataegus monogyna* (Hawthorn).

Soil profiles were created in each of the areas and photographs of these are presented in **Plate VIII, Page 38 and Plates IX, X, & XI, Pages 46-8**.

4.2 Method.

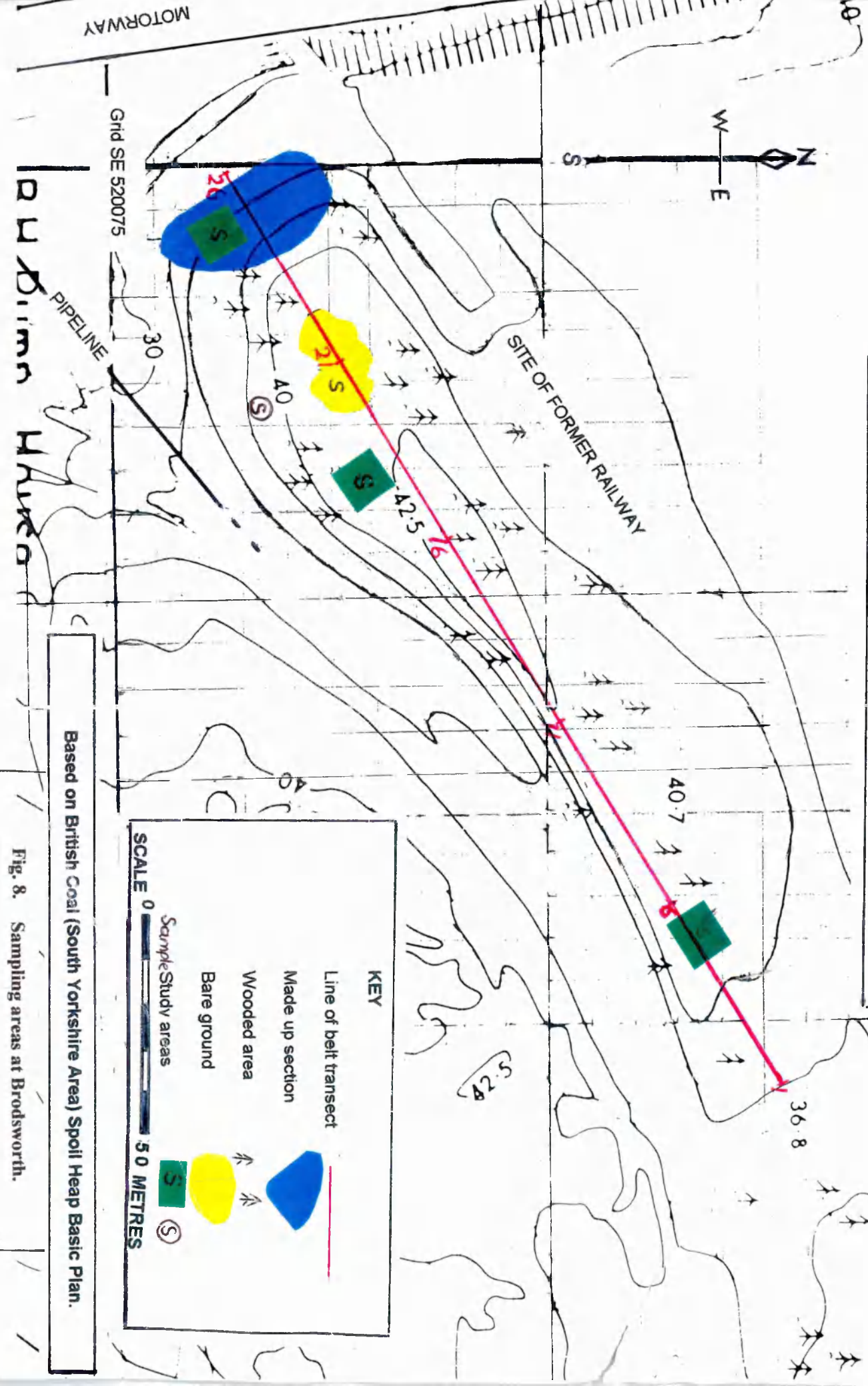
Random locations were chosen within the defined areas and three samples (1kg approx.) taken at different levels at each site. A surface sample (maximum depth 3cm), a second sample between 4 and 8 cm deep, with a third sample from 15 to 25 cm deep. These were collected using a trowel and placed in polythene bags for transport to the laboratory.

A further sample was taken from a cutting at the south side of the tip to investigate pH at the core of the tip. Here a sample was taken by digging into the side of the cutting, a metre below the surface. Samples were labelled 1 - 10.

The samples were taken to Hallam University (School of Leisure and Food Management), where standard MAFF analytical tests (HMSO 1974, Bouyoucos 1927, 1928), were applied under supervision to determine the nutrient status.

BRODSWORTH PIT TIP

(Tipping 1905 - 1925 approx.)



Based on British Coal (South Yorkshire Area) Spoil Heap Basic Plan.

Fig. 8. Sampling areas at Brodsworth.

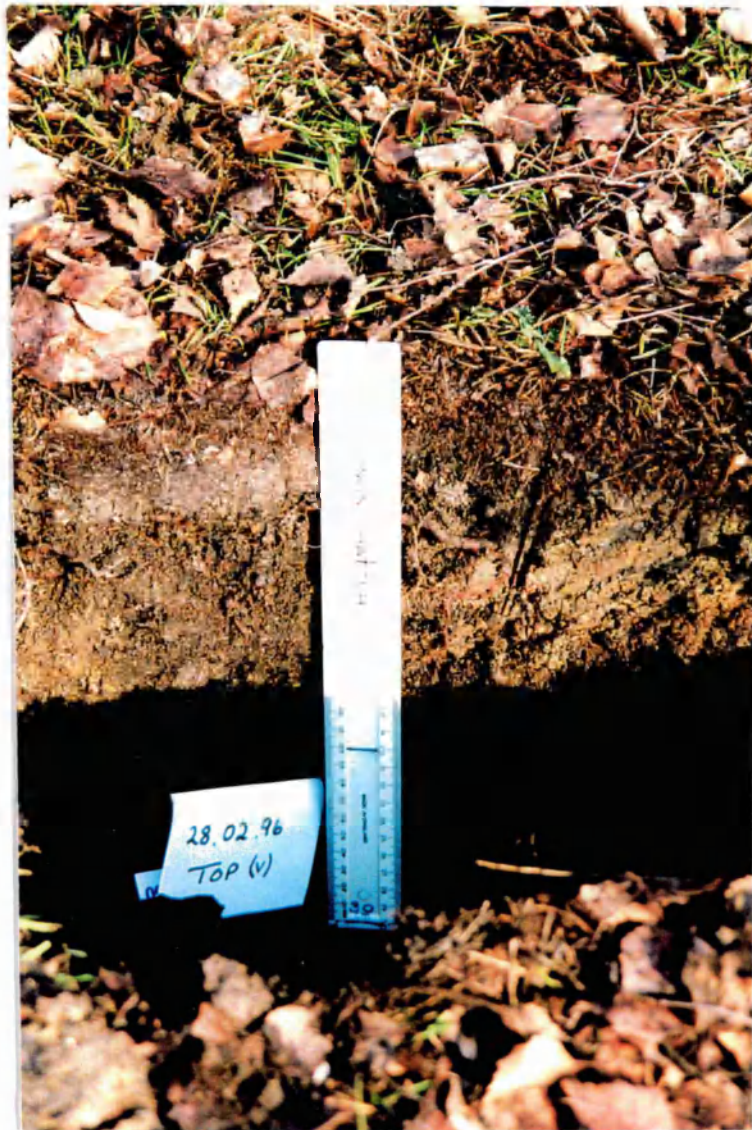


Plate IX. Profile of the vegetated part of the top of the tip.



Plate X. Profile of the east end which includes cinders.

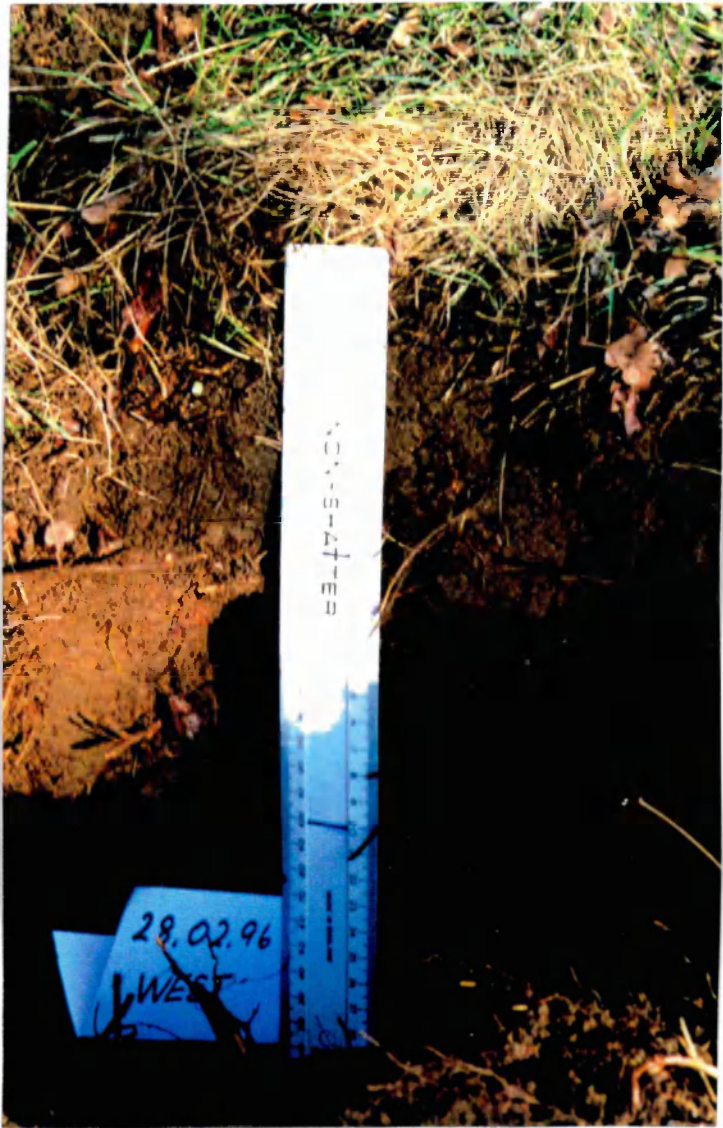


Plate XI. Profile of the west end which has introduced soil on top.

4.2.1. The MAFF analyses.

The general aim of this research is to investigate the usefulness of earthworms in the amelioration of colliery spoils to useful growing media and their effect on plant available nutrients.

Literature review has illustrated the general lack of standardised approach to methodology for the analysis of plant available nutrients. Different workers have used various nutrient extracting agents which leach the nutrients with different efficiencies. Also there appears to have been no standardised approach to expression of concentration units, consequently data interpretation, and comparison of experimental data with other researchers is difficult.

Since plant available nutrient status is a prime consideration of this work it was decided to use the tried and tested analysis methodology designed specifically by MAFF (HMSO 1982, HMSO 1988a, HMSO 1988b), for the use in crop response to nutrient application studies. The analysis methods, together with their interpretive data (HMSO 1988c), have been used unmodified for many years in comparative studies by MAFF/ADAS. In developing their methods MAFF/ADAS scientists held the philosophy that plants grow in a volume of soil rather than a mass of soil. Hence the analyses are carried out in unit volumes of air dried soil which have been ground to pass a 2mm sieve. This philosophy is most meaningful to MAFF's end use of the data which is to make amendments based upon mass of fertiliser to volume of soil applications. (A mass, or weight, of fertiliser being supplied to an area of soil to a root depth of 15cm, to restore a nutrient to optimum concentration).

It must be remembered though, in interpretation that this methodology was designed for use in agricultural studies where optimum cropping yields were determined as a function of applied nutrients. In natural situations the soil concentration of plant available nutrients are normally found to be in deficient

quantity, for agricultural crops, but not necessarily for natural herbage, such as scrub, grass, or woodland.

In order to determine these requirements, the amounts of available nutrients present are determined in mg l^{-1} . Unfortunately, to alter these quantities to $\mu\text{g g}^{-1}$ would entail mixing analytical methods of determining proportions such as the use of different extractants, and so could not be considered accurate or comparable. (Although it is possible to use specific gravity, in this case 1.95 the mean of 10 samples, to change mg l^{-1} to $\mu\text{g g}^{-1}$).

The question of the proportion of nutrients in arable soil for comparison brings in many variables, as soil contents change according to past history, present use, and seasonal variation. Pasture too can be varied for other reasons besides the origin of the soil. In respect of nitrate for example in the nitrogen cycle, the actions of *Nitrosomonas* and *Nitrobacter* in forming nitrites and nitrates are dependent on the temperature being between 5°C and 30°C , where a 10°C rise can have a threefold effect, the availability of oxygen which can be reduced by waterlogging, and pH which needs to be above 5. Microbes would also need an energy source available in suitable forms of carbon, nitrates and phosphates (HMSO 1982, HMSO 1988a, HMSO 1988b).

Nutrients can be leached out, and sometimes reincorporated in soil by capillarity. The results used here indicate the conditions for the samples taken in January 1994. To determine the nutrient status of the spoil more accurately would require many repetitions over a long period.

4.2.2. Procedure.

In the laboratory, large stones were picked out and the samples were air dried. Lumps were removed by grinding with a mechanical mortar mill, to pass through a

2mm sieve. Samples were ground to this size to avoid complete disruption of the soil structure. There were no replicates of the samples.

The MAFF analyses methods determine the amount of ions available to plants as mg l^{-1} of soil, for agricultural purposes. The specific gravity of the spoil was found by displacement to be 1.95 (mean of 10 samples). If this ratio is divided into the quantities of ions found in the spoil, an equivalent value as $\mu\text{g g}^{-1}$ (ppm) will be found.

The accuracy of this ratio might be questioned as in the MAFF tests the samples were dried and ground, however the samples used to determine the specific gravity were dried but not ground, suggesting that some voids within the samples might not have been wetted.

4.3.3. Analyses.

After air drying, the MAFF procedures were strictly followed under supervision in the laboratory at Sheffield Hallam University. The methods used for each of the tests are outlined here.

1. pH tests on the Brodsworth samples were carried out using a standard electronic pH meter with buffers for pH7 and pH4.
2. Soil organic matter was determined by burning in a muffle furnace at 450°C for 4 hours. The ignition was continued to a constant weight.
3. When the Brodsworth samples were examined for texture, they were first dried before particle sizes were determined using a soil hydrometer. Samples were prepared and dispersed in water by the standard method with hydrometer readings taken at 46 seconds and 5 hours. No correction for temperature was necessary.

4. Soil conductivity was measured by extracting soluble salts from the samples with a saturated calcium sulphate solution, which extracts all salts other than calcium sulphate. The conductivity of the filtered extract was determined using a conductivity cell and meter.
5. Plant available nitrate-nitrogen, NO_3^- , was extracted from the spoil samples with distilled water and the filtered solution was analysed by Ion Exchange Chromatography.
6. Plant available phosphate, H_2PO_4^- , was extracted from the samples using Olsen's reagent. The concentration of phosphate phosphorus in the extract was determined by the technique of Molecular Spectrometry utilising a UV-VIS Spectrometer.
7. Plant available Potassium, K^+ , was extracted from the samples by molar ammonium nitrate solution and the resulting solution, after filtration was analysed for potassium by Atomic Emission Spectrometry using a Flame Photometer.
8. Calcium and Magnesium were extracted from the samples in the form of Ca^{2+} and Mg^{2+} ions by molar ammonium nitrate solution. The resulting solution, after filtration was analysed by Atomic Absorption Spectrometry.
9. Sulphate, SO_4^{2-} and Chloride, Cl^- , were both determined by Ion Exchange Chromatography (HMSO 1974).

4.3 Results.

4.3.1. Soil pH.

Initially the shales when tipped would have had a neutral pH, as was shown by testing freshly deposited colliery spoil at neighbouring pits, Markham Main, GR

Table iii.

Sam- ple	pH	Org %	Texture	conduct- ivity, micro- siemens	N mg ⁻¹ soil	P mg ⁻¹ soil	K mg ⁻¹ soil	Ca mg ⁻¹ soil	Mg mg ⁻¹ soil	SO ₄ mg ⁻¹ soil	Cl mg ⁻¹ soil	Location, depth & comments. (Air dried, ground spoil <2mm)
1	4.8	73.6	fibrous	1953	5	0	82.5	802.5	126.25	38	34	Vegetated part, 3cm, fibrous.
2	4.1	31.6	clay/loam	1913	28	2	115	250.0	57.5	58	32	Vegetated part, 4-8cm, less roots, clayey.
3	3.6	21.8	clay	1869	26	0	106	175.0	60.0	115	41	Vegetated part, 15-25cm, no roots, clay with shale.
4	3.5	29.3	clay	1924	2	4	115	150.0	47.5	91	19	Bare part, 3cm, mosses, compacted clay & shale.
5	3.2	27.8	clay	2085	2	2	52.5	412.5	63.75	269	21	Bare part, 4-8cm, compacted clay and shale.
6	3.0	44.9	clay/loam	2353	2	2	50	875.0	66.25	2077	17	Bare part, 15-25cm, grey/green clays, shale & coal.
7	7.1	24.1	loam	2065	7	6	412.5	2150.0	587.5	86	37	West end, 3cm, topsoil, healthy roots.
8	7.5	18.8	loam	2035	7	6	295	2500.0	550.0	62	32	West end, 4-8cm, topsoil, fewer roots.
9	7.0	19.4	clay/loam	2235	27	4	95	3562.5	380.0	8000	61	West end, 15-25cm, topsoil, grey clay.
10	2.8	47.0	loam	2805	3	4	26.25	8125.0	107.5	9385	15	Side, 1metre, grey/green clays, shale & coal.

SE617042, and Rossington, GR SK600975, in 1993. These samples were tested using BDH Universal Indicator solution.

As is seen from the table of results (see **Table iii., Page 53**), acidity increases with depth, due to oxidation of pyrite in the shales. Other researchers have shown that at greater depths pH begins to rise again, no doubt due to less oxidation having taken place. Costigan *et al* (1981), in their analyses of some 20 sites stated that most spoils were compacted with a high clay content, and pyrite oxidation took place in a shallow surface zone resulting in material of low pH and low pyrite content. The underlying unoxidised zone exhibited high pH and high pyrite levels.

The graph (see **Fig 9, Page 55**), suggests an inverse relationship between pH and the development of sulphate ions over time in the tips studied by Down (1975). Allowance must be made for the samples being collected from different sites. With the exception of one plot (pH 9 against sulphate 30.6 ppm, which was taken in fresh spoil before pyrite oxidation had begun), there is a strong suggestion of an inverse relationship.

4.3.2 Organic Matter.

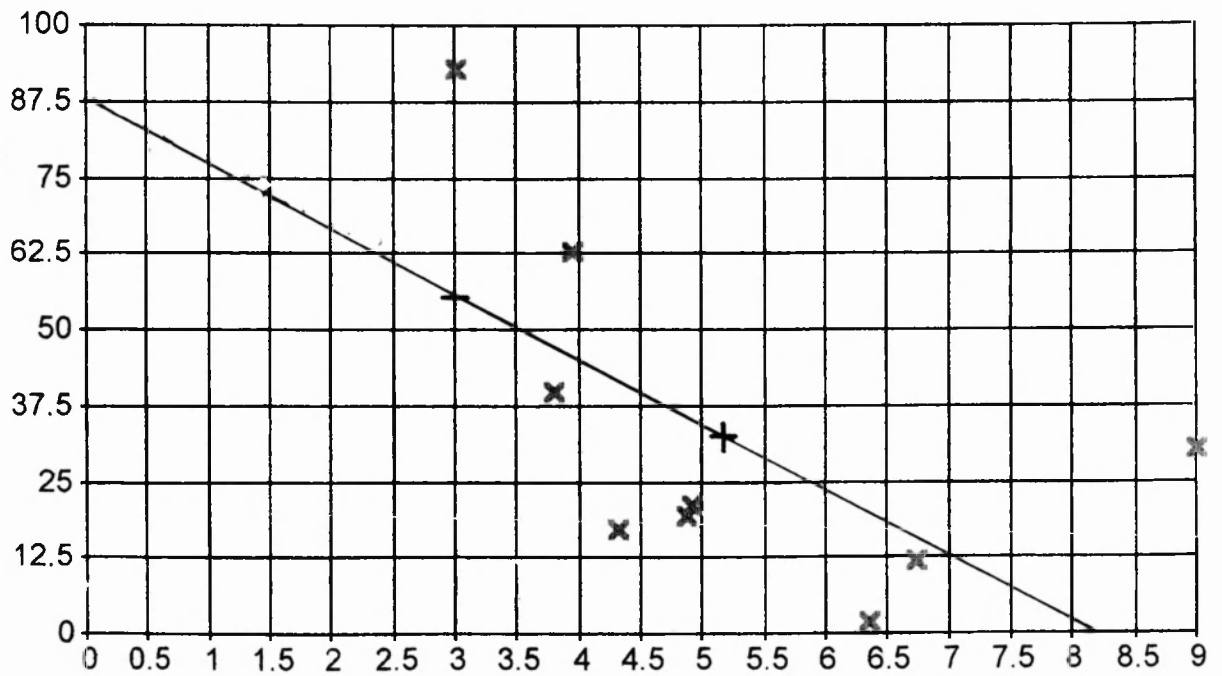
Sample 1 from the top 5cm of the vegetated part of the tip contained a large amount of root material and on burning showed an organic content of 73.6%. In other samples there was less than 50% organic material as would be expected where there were no roots or leaf litter. However, in samples 6 and 10 where organic contents of 44.9% and 47.0% respectively were found, pieces of coal were seen indicating that the organic content was not in a form which could be utilised by plants.

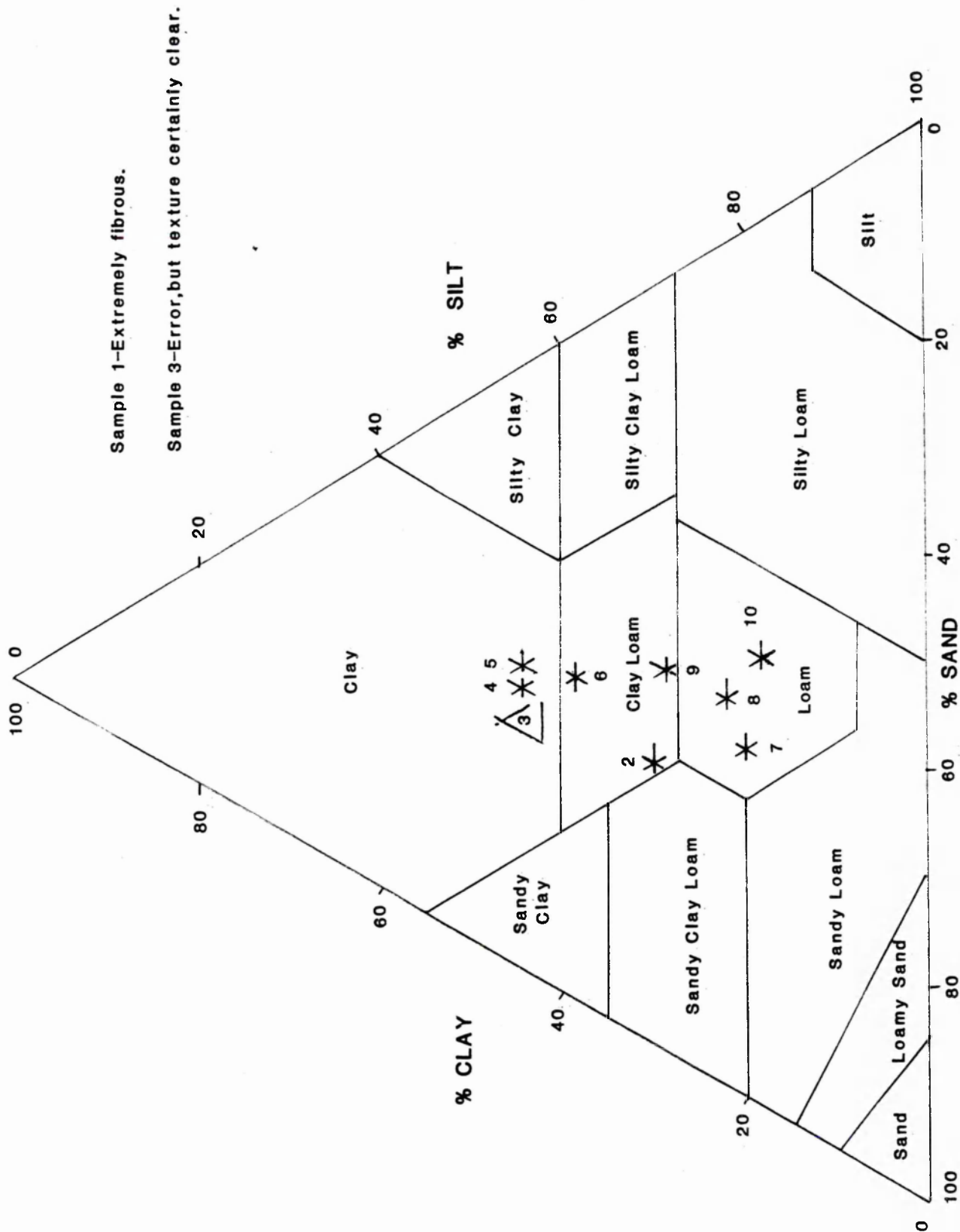
4.3.3. Texture.

The results are shown in **Table iv** and in **Fig 10** page 56.

Fig. 9. pH and Sulphate on colliery spoil over 178 years.

X axis, pH. Y axis, Sulphate ppm.





SOIL SAMPLES, BRODSWORTH SPOIL HEAP

FP Jan 1994

Fig. 10.

Table iv. Proportions of sand, silt and clay in Brodsworth spoil samples.

Sample	1	2	3	4	5	6	7	8	9	10
%Sand	-	44	32	30	28	32	48	42	36	40
%Silt	-	26	22	26	28	30	32	36	36	42
%Clay	-	30	42	44	44	38	20	22	28	18

In these results particles from 2.0 to 0.06 mm are sand sized but are unlikely to resemble sand in any other way being derived from shale. Shales and clays contain flat crystals of such minerals as kaolinite, montmorillonite and illite. Clay minerals, because of their lattice structure have a negative charge which enables cations to be adsorbed around the edges. Sands on the other hand, consist mainly of inert quartz crystals, which are made of silicon-oxygen tetrahedra in a three dimensional framework (Mason 1966). The clays appeared dark grey and occasionally greenish yellow. The presence of clinkers suggests that combustion, spontaneous or deliberate had taken place at some time. None of the shales were red.

All samples appear in the clay or clay loam parts of the graph (see **Fig 10, Page 56**), in contrast to Richards *et al* (1996). In their graph, the Midlands coarse discard appears in the sandy clay loam, while the fine discards are in the sandy loam. Bradshaw and Chadwick (1980), also placed the Yorkshire colliery spoil in sandy loam area. The difference in the size is considered to be due to the Brodsworth sample having been subjected to a longer period of weathering resulting in the production of smaller particles.

Down (1975), examined surface samples from 55 year old and 98 year old tips in Somerset (similar age to Brodsworth), and found that they also had a sandy texture. This strongly contrasts with the clays and clay loams of the Brodsworth

spoil. Down (*op cit*), noted that below a depth of 20 cm, there was no significant breakdown of spoil in heaps as old as 98 or 178 years.

Although the composition of the spoil heap did not resemble what might be normally considered as soil, plants were growing on it. As a plant-growing medium it can then be considered an incipient or potential soil. Instead of bedrock or drift underlying as the parent material, a mixture of Coal Measures rocks, mainly shales, have been deposited which are in varying states of weathering and decomposition. Rimmer and Colbourn (1978), noted that naturally occurring soils developed from Carboniferous shales, suffer in a similar way to spoil heaps, being dense and alternating from waterlogging to summer drought. Plants alone are unable to penetrate far into the compacted spoil and roots will die in the saturated zone above the compacted layer, resulting in development of a very shallow rooting system.

4.35. Conductivity.

The degree of salinity of the soil is measured by its electrical conductivity. A low conductivity - less than 1900 microsiemens, or a high conductivity - more than 2700 microsiemens (m.mhos per cm), could restrict growth of plants, especially seedlings (Richards *et al* 1993). While most of the samples fell into the range which would not limit growth because of salinity levels, there were two noticeable exceptions:

Sample 3, from a weathered shale below a woodland dominated by *Betula*, had low conductivity but did not appear to lack salts. The sulphate content was greater than most of the samples with the notable exceptions of those which appeared to be least weathered. In an unpublished paper, Woodhouse (*pers com*), has shown a correlation of 0.97 for sulphate and conductivity on coal spoil in the Dearne Valley.

Sample 10, from weathered shale at a depth of a metre below the surface of the tip where sulphates were in high concentration, presumed to be due to the breakdown of pyrite, would not be suitable for plant growth. Sample 10 with its conductivity of 2805 microsiemens, from a range of 1869 to 2353 microsiemens for the other samples, raises the question whether this is due to accumulated salts leached from upper levels, or if it is part of a general increase in salts, particularly sulphate. This question would be answered by taking samples from greater depths, as well as additional samples between 0.25 and 1metre.

The results suggest a lack of ions in the top 25 cm over the tip due to leaching. Leaching would have been a steady process since tipping stopped, as the established trees indicate that no large scale disturbance of the tip has taken place to expose fresh shales which would increase acidity.

4.4. Chemical Analysis.

In order to get a picture of the development of the site, the first sample to consider will be number 10, which represents the least altered material.

Sample 10.

The high organic content of this sample is due to fossil organic substances in coal, which are inert, and do not enhance the structure as does humus.

The structure is classified as loam but as noted earlier this is purely a reference to particle size; the centre of the tip does not resemble a true loam such as garden soil.

This has the lowest pH, consistent with the presence of iron pyrite (FeS_2).

Weathering of pyrite produces several substances including FeS , FeSO_4 and S ,

which reduce the measured pH. This is reflected in the high conductivity measured for this sample. The three main plant nutrients were present in very small proportions in this sample, while there was ten times as much Ca present than in the vegetated part. The amount of Mg was similar to that in the vegetated part and there was half the amount of Cl. The SO_4 content in all the unaltered parts was high, but this sample contained almost 250 times that found in the vegetated part. Any notable nitrate nitrogen content would not have been expected from this sample as no source has been recognised.

Samples 1, 2 & 3.

These sample are in contrast to number 10, being that part of the colliery spoil which is best supporting plant growth. The herb layer under the birch provides fibrous material which makes for a soil with a high organic content in sample 1. This pH is in the acid range but not so low as to prevent growth. The presence of dense roots contrasts with the absence of phosphate phosphorus, from which it must be concluded that any P which becomes available is immediately used by vegetation. Potassium is three times that of sample 10 arising from weathering of shale. The Ca content is only 0.1 times that of sample 10, while the Mg is similar. The sulphate ion content is low presumably leached out. The N content is low, as expected since useable nitrogen forms in soil as NO_3^- and NH_4^+ are very soluble and are quickly used or leached out.

Sample 2, the subsoil of sample 1, shows a slightly lower pH, due to the slightly higher SO_4 content. Organic content is half that of the topsoil. The organic content is humus rather than fibre, with N at 28 mg l^{-1} K is also increased, with Ca and Mg both being reduced by about 30% and 50% respectively.

Below the upper layers, a change begins. With a pH of 3.6 and SO_4 content up to 115ppm, this well weathered sample is definitely beginning to show similarities with the high acid interior of the tip. Nutrients are mainly similar to the sample from

immediately above but while calcium has dropped, magnesium has slightly increased its proportion. With no living or dead material to be seen, the measured organic content was still 21.8%. This was presumably due to coal fragments being present.

Samples 4, 5 & 6.

These samples were taken from part of the tip which had only mosses growing on it, a gap within the canopy of the wooded top of the tip. The surface sample had a pH less than a surface sample only a few metres away and slightly lower nutrient levels. Both SO_4 and Cl were lower too, presumably washed away from the surface. As expected, the similarities with sample 10 increased as lower levels were tested. pH dropped and SO_4 levels rose sharply. K levels fell and Ca and Mg levels rose. Even so there was still a 10x difference in Ca from sample 6 to sample 10. The PO_4 content in these samples was higher than in samples 1, 2 & 3 as it was not being taken up by the plants.

Samples 7, 8 and 9.

These samples appeared brown rather than grey. They are very different from the rest of the samples. pH on the surface is 7.1 becoming slightly alkaline just below the surface and returning to neutral at 20cm deep. Samples 7 and 8 have higher nitrate, phosphate and potash content than the rest of the tip, possibly due to the soil being introduced from arable land, and the ions have circulated between soil and plants since that event. The nitrate content increases at 20cm deep due to leaching. K levels fall somewhat below the surface from 425mg l^{-1} . The high proportions of calcium and magnesium are due to the overlain soil being derived from the Magnesian Limestone. The most surprising change is in the Sulphate content. Between the surface and 20cm deep the SO_4 content increases a hundredfold, demonstrating just how near the underlying very active spoil is to the surface.

The results from the west end of the tip contrast with those from other parts of the tip and suggest that a mature soil has been spread there. This possibly took place when the tip was shortened due to the building of the A1(M) trunk road.

The sulphur as sulphate ions varied widely from 38mg l^{-1} in the *Betula* area to $9,385\text{ mg l}^{-1}$ at a metre below the surface. While this can be explained as being due to the oxidised pyrite, the level of $9,000\text{mg l}^{-1}\text{ SO}_4$ a mere 20 cm below the surface at the west end suggests that this part has not had the sulphate leached away. When the tip was shortened the leached top was removed exposing the sulphate-rich spoil, it was immediately sealed in by the cover of new soil. As the resulting slope is quite steep, rainwater would tend to run off the surface rather than percolate through and leach the sulphate. Thus the sulphate level would remain high despite its proximity to the surface.

The problems caused by the presence of pyrite in colliery shales are not easily solved. Pyrite is present in some sedimentary rocks due to the release of H_2S from decaying matter in reducing conditions. As shown above, the presence of pyrite leads to extremely acid conditions in the spoil heap, when it is exposed to air. In South Yorkshire coal spoils, pyrite appears both in nodules and disseminated forms which are not evenly distributed throughout the spoil. Hence areas in close proximity demonstrate widely varying sulphate and pH levels.

The rate of acid production is largely determined by the mechanism of pyrite oxidation (see Chapter 1.) Chemical oxidation is relatively slow compared to biological catalysed oxidation.

Provided air can be kept away from the pyrite, then oxidation, leading to acid formation will not occur. Some authorities suggest capping spoil heaps containing pyrite to prevent oxidation Humphries *et al* (1994), suggest that Pyrite can be protected from acidification by 0.5m of soil cover. Considering the size of some of

the South Yorkshire spoil heaps, where pyrite is likely to be present, this proposal would appear formidable, even though capping would prevent the run off of acidic water, but may not prevent acid leachates.

The shales do weather to a clay however, and this will provide some level of sealing, although earthworm activity and the growth of tree roots are always likely to break through the clay, introducing air and water to the unweathered parts below. Some level of acid production must be accepted until weathering of shale to clay is completed.

Chemical oxidation of pyrite surface layers can be retarded by reducing oxygen availability by compacting the spoil, capping with clay, or by avoiding disturbing the surface of the spoil. Backs *et al* (1993), have shown that biological oxidation of pyrite can be inhibited by the incorporation of large quantities of organic matter into the spoil. Several waste products (eg sewage sludge, chicken manure, mushroom compost, leaf litter), have been researched, with each showing a beneficial effect. Apart from having the affect of inhibiting the oxidation of pyrite, the incorporated organic matter provides a nutrition source for an inoculated worm community.

Costigan *et al* (1982), have shown the attendant difficulties associated with liming acid spoil, as the lime leaches down the soil profile slowly unless physically incorporated using expensive machinery. Moreover, as lime is washed to lower levels, through worm burrows, it will change the solid clay to a crumbly structure, as it flocculates the clay particles. This change in texture would enable water and air to percolate through to unweathered parts where pyrite is present. The resulting increased aeration of unreacted pyrite further within the heap would restart acid production at lower levels. Lime addition needs careful consideration.

4.5. Plant Nutrients.

Of the three nutrients in soil considered to be the most important to plants, (nitrates, phosphates and potash,) phosphates are least accessible.

4.5.1. Nitrate-nitrogen.

For nitrogen to be supplied to vegetation there has to be a steady supply of ammonium to be nitrified, as the amounts of mineral nitrogen and nitrogen from rain are relatively small ($\pm 20\text{kg ha}^{-1}\text{yr}^{-1}$). The pH of the soil must also be high enough for nitrification to take place. Both ammonia production and raised pH are effected, in part, by the action of earthworms. Syers and Springett (1984), quoted by Killham (1994), support this statement:

"Of particular importance in the mineralisation process in less acid soils are the earthworms and their interaction with soil microbes. Lumbricid worms significantly increase the mineral nitrogen content of soil."

The nitrogen levels in these samples range from 2mg l^{-1} to 28mg l^{-1} . The higher levels are in the subsoils of vegetated areas, while the lower levels are in those locations where there are either no plants or only moss. At Rother Valley a range of nitrogen levels which went from a trace to 60.75mg l^{-1} over ten samples were found (Summon 1984).

Stevenson (1982), listed five ways in which microbial breakdown of organic substances can be limited.

"1. Stabilisation of proteinaceous constituents (eg amino acids, peptides, proteins) through their reaction with other organic soil constituents (eg lignins, tannins, quinones, reducing sugars).

2. The formation of biologically resistant complexes by the chemical reaction of NH_3 or NO_2 with lignins or humic substances.

3. *Protection of organic N compounds from decomposition by their adsorption on to clay minerals.*
4. *Stabilisation of Organic N compounds by the formation of complexes with polyvalent cations.*
5. *The siting of organic N in pores or voids physically inaccessible to microorganisms.*

The significance of these mechanisms will be greater in infertile soils."

1. and 2. from the above both suggest that nitrogen can be diverted into humus. NH_3 and humus materials are together in the earthworm gut so the possibility of the two combining can be envisaged.

4.5.2. Potassium.

The total potassium, (K^+) present in arable soil in the proportion of 0.2 - 0.4% (2,000 - 4,000ppm). (Jacks 1954), compared with 50 - 400mg l⁻¹ on Brodsworth Tip. These ions are derived from Illite and are considered to be adequate.

4.5.3. Phosphate-phosphorus.

Phosphorus occurs in similar proportions in arable soil (Russell 1932). It was noticed that the relative proportions of phosphate-phosphorus were very small compared with nitrate and potash. Mason (1966) showed that shales contain 1700 ppm (0.17%) P_2O_5 from clay minerals. The main mineral source of Phosphorus from Apatite is not available in this situation. Phosphorus in the available form phosphate (PO_4^-), normally arises from decomposition of organic residue but there were few organic sources in the raw tip. It is possible in this situation that phosphates could have come from fossil organic sources. Epstein (1972), states that phosphate is held as an exchangeable anion by clay minerals and may be fixed in forms available for the absorption by plants. He also says that phosphorus is absorbed in the main as the dihydrogen phosphate ion, H_2PO_4^- , which at pH5 is 99.3% soluble. Pulford and Duncan (1975), state that colliery spoil is deficient in

plant available phosphate as the spoil can adsorb large quantities on to oxide surfaces. Pulford *et al* (1984), showed that P was deficient in a spoil/grass system and was not aided by the application of a phosphate fertiliser. In the colliery spoil heap there is a further complication as regards P. When spoil is weathered, pyrite, it has already been noted, lowers the pH due to the formation of sulphuric acid. The acid conditions break down the clay minerals releasing aluminium (Al) and magnesium (Mg). These can become phytotoxic limiting plant growth. Any phosphate ions present will react with iron from the pyrite to form insoluble ferric phosphate. Phosphate ions can also combine with aluminium producing aluminium phosphate which is also insoluble. The presence of aluminium in acid conditions depresses the uptake of P. Both high and low pH will decrease the availability of P. The problem faced by plants in obtaining phosphorus, can be alleviated by a symbiotic relationship between some plants and mycorrhizal fungi. Davis *et al* (1992), when describing the relationship, spoke of:

" Some are well known such as Amanita muscaria (Fly Agaric,) which forms a mycorrhiza with birch, and is therefore almost always found growing under birch." (Davis *et al* 1992).

Evidence of fungal growth is to be seen at Brodsworth (see **Plate XII, Page 67**).

This symbiotic relationship between fungus and birch may have assisted in establishing vigorous growth on the tip. Fungal hyphae penetrate the soil and collect phosphate ions transporting them back to the sheaths around the roots.

The effect is twofold in that:

the available root area for collecting phosphate is vastly increased, and

the transportation of ions along the hyphae is much faster than diffusion through soil.

With mycorrhizal help, birch becomes an efficient coloniser of poor soils, and the conditions provided on a spoil heap are overcome by this combination.

Plate XII . *Amanita muscaria*
growing with *Betula* sp. Brodsworth.



Formation of an adequate root system which can support a tree or shrub without this fungal system of support normally requires a horticulturalist to supply phosphorus, in the form of bonemeal, when planting trees (Hessayon 1990).

4.5.4. Other Nutrients.

The calcium levels are high. Of the clay minerals, Glauconite can contain some Ca and Mg cations, but these would not explain the 8125ppm Ca found. Again, Montmorillonites can contain Ca and Mg when K is low. These could have been formed from the muds which covered the coal if conditions at the time were alkaline. Recent acid conditions could have made both the Ca and Mg (along with aluminium ions), available in large amounts. White (1987), states that the weathering of clay can lead to the replacement of K^+ by cations of higher ionic potential such as Ca^{2+} and Mg^{2+} which form outer sphere complexes on the surfaces, and are freely exchangeable with other cations in the soil solution. What we can be sure of is that the Ca and Mg in this sample do not owe their origin to the local Magnesian Limestone as there is no connection between them. Mason (1966), says that shales contain 2.44% MgO and 3.11% CaO. The occurrence of chloride ions is probably due to its presence in Magnesian Limestone as $CaCl_2$ or $MgCl_2$ in samples 7 and 8 with further leaching into sample 9. Other samples possibly originated as NaCl in the shale, but not from marine bands in the Coal Measures as none are noted in this part of the strata.

4.7. Characteristics of some soil types.

Allen (1989), listed typical levels of extractable elements in mineral soils, see **Table v** (In $mg\ 100g^{-1}$), page 69.

Table. v, Typical levels of extractable elements in mineral soils.

Element	Low	Medium	High
(mg 100g ⁻¹)			
Potassium	10	10 - 30	30
Calcium	10	10 - 200	200
Magnesium	5	5 - 30	30
Ammonium-nitrogen	0.5	0.5 - 2	2
Nitrate-nitrogen	0.2	0.2 - 1	1
Phosphate-phosphorus	0.2	0.2 - 2	2

Two of Allen's typical examples of soil types are also of interest (op cit). Although they differ from spoil, they show the changes from a young mineral soil to a mature forest soil.

Table. vi, Examples of mineral soils.

	pH	mg 100g ⁻¹					%	
		Na	K	Ca	Mg	P	C	N
Brown Forest Soil	5.4	8	19	25	17	0.9	8	0.4
(Shropshire)								
Skeletal Montane Soil	6.2	1	2	3	1	0.1	1	0.1
(Cairngorms)								

4.7. Soil Structure.

On the wooded parts, Brodsworth tip exhibits a well maturing soil, with a structure whose horizons are as follows:

O - O _L	Organic litter layer
- O _F	Organic decomposition layer
- O _H	Organic humus layer
A - A _H	Mineral horizon of maximum biological activity with high organic content. Leaching layer.
C -	Parent material.

The parent rock, shale, has been broken and dumped on the site so that the C horizon is physically modified and might be regarded as an extremely thick B horizon. Such horizons are mid profile being a transition layer between unaltered rock and a mineral soil A.

This structure does not fit within a normal classification of soil. It comes closest to either:

a Peat Ranker, with horizons O and C;

or a Brown Ranker with horizons A and C.

Over a long period of time it is conceivable that biological activity would establish a structure close to horizons A, B, C, a Brown Earth. This could occur as a mineral horizon where a biological activity is already present, and a mid profile layer different from A could form by transported humus introduced by earthworms from the O and A layers to C. This new layer would be defined as a B horizon, giving a Brown Earth structure.

A Brown Earth (Forest), soil does not have clear divisions in its horizons. One layer gradually changes into the next, as a deep dark brown organic horizon merges into lighter coloured mineral soil over altered parent mineral (White, 1987), unlike a Peat Ranker or a Brown Ranker where divisions are clear. At Brodsworth, while the O horizon is clearly separated from the others, change at lower levels is more gradual.

The development of a Brown Earth would depend on the ability of earthworms to penetrate the C horizon, It has been found by analysis that the C horizon at Brodsworth is quite acid, pH 2.8 (see **Table iii., Page 53**), and this limits the species of earthworms able to survive the acid conditions. (See **Figs 1&2, Page 16**).

Lumbricus terrestris, a burrowing worm, is not normally found in pH less than 6.2 (Sims and Gerard, 1985), but *Eisenia fetida* can tolerate pH as low as 4.3 (op. cit). Horizon A in birchwood at Brodsworth has a pH of 4.8 (Soil analysis), and is within its range of tolerance. *Eisenia fetida* is not regarded as a burrowing worm, rather an Épique, or litter dweller (Bouché 1977). These smaller species could begin an enrichment of the top part of the hostile C horizon, forming a B horizon.

If dead plant material is to be added to a spoil heap in order for a soil to be formed, the following processes need to take place:-

1. The plant material needs to be comminuted - broken up into small fragments, to increase the surface area for microbes to act upon.
2. The fragments of plant material need to be mixed with the mineral particles, so that a clay humus complex can be formed and a store of plant nutrients made for subsequent vegetation.
3. The mineral particles need to be separated to enable excess water to be drained and permit air to permeate the substrate.
4. Clay particles need to be formed into water stable crumbs to enable aeration and drainage, noted above, to be sustained.

5. The microbial biomass needs to be increased and spread throughout the dead plant material so that the organic matter can be quickly decomposed.

Each of the above requirements might be provided by the introduction of earthworms.

4.8. Summary.

The limitations to plant life in spoil on the main tip are:

1. The very low pH.
2. Conductivity beyond the range which will support growth.
3. Higher sulphate levels than can normally be tolerated by plants, and,
4. In acid conditions, phosphorus becomes fixed by combining with iron forming FePO_4 , and aluminium from the clay minerals forming AlPO_4 .

These are the conditions which might be overcome by the application of earthworms together with a foodsource.

Chapter 5.

AN INVESTIGATION INTO THE DIVERSITY OF PLANT SPECIES ON THREE DIFFERENT AREAS OF BRODSWORTH TIP.

5.1 Introduction.

The interaction between plant growth, soil formation and earthworm activity suggests that there might be some correlation between plant species growing on the tip and earthworm populations. There appears to be some difference in plant types at the west end of the tip where alterations were made when the motorway was constructed. Greater diversity in plant species between different parts of the site might lead to differences in earthworm populations, or vice-versa.

5.1.1 Line Transect .

After an initial visit to identify the different species of plant growing on the site, it was noticed that the tip appeared to be divided into three distinct sections which could be compared with each other:

- i) The eastern end of the tip, which is the oldest part.
- ii) The top of the tip which is the youngest part of the spoil section of this area.
- iii) The western slope which appears to have been made up with local soil after alterations. (See **Fig. 8, Page 45**).

Lists of plants found on the tip are shown in **Appendix 2**.

5.1.2. Method.

On each of the sections a ten metre length of line marked at one metre intervals was used to carry out a line transect. At each interval the species of plant coinciding with the point was recorded. This was repeated at one metre intervals giving 100 point locations on each of the chosen sections, giving 300 locations in total. Simpson's Diversity Index (eg Cadogan and Sutton 1994). was used to determine the comparative richness in flora on the sections, because of its simplicity. Simpson's

Index is a simple method of comparing diversity in different areas, based on the probability of two specimens picked at random in a community of infinite size being the same species (Krebs 1994). The method is easier to use than the Shannon-Wiener function, but gives relatively little weight to the rare species and more weight to the common species, according to Krebs (op cit). Eight transects were completed between June 1994 and June 1996.

5.1.3 Results.

The species found, and their individual frequencies are shown in **Table vii. Pages 75 & 76.** **Table vii.** is composed of the field results for June of each year, discounting the litter and bare patches. These lists, together with **Figs 11, 12 & 13, Pages 76-79,** indicate that the variation in diversity of species (as measured by Simpson's Index), which was shown in June 1994 between the three parts of the tip, continues through the year.

Fig 11. shows diversity over the whole year; grasses were classified as a single species since it was not possible to separate them accurately by species during the early months.

Fig 12. compares the month of June in 1994, 1995 and 1996 when the grasses were flowering, so it was possible to count all species noticed. These tables need further amending because the numbers for litter and bare patches were included and these relate more to ground cover than to actual species present.

Fig 13. compares the results with all records of litter and bare patches omitted.

The summer of 1995 and the spring of 1996 were drier than average, resulting in fires on the top of the tip. There was an increase in the amount of bare patches and litter

Plants found on Brodsworth tip. June '94, '95 & '96.

[illegible]

Table vii . continued.

<u>C indicates calcicole.</u>	<u>1994</u>			<u>1995</u>			<u>1996</u>		
<i>Inula conyza</i>									
<i>Leontodon sp</i>									
<i>Leucanthemum vulgare</i>			2			2			2
<i>Lotus corniculatus</i>			4						
<i>Medicago lupulina</i>			2			4			4
<i>Ophrys apifera</i> (C)									
<i>Pilosella officinalis</i>	3	1	2						
<i>Pimpinella saxifraga</i> (C)									
<i>Plantago lanceolata</i>			7			11			14
<i>Primula veris</i> (C)			2						
<i>Ranunculus acris</i>									2
<i>Ranunculus ficaria</i>									
<i>Rhinanthus minor</i>			6						
<i>Rumex acetosella</i>	6			1		4			1
<i>Senecio squalidus</i>									
<i>Senecio vulgaris</i>									
<i>Senecio jacobaea</i>			2						
<i>Stellaria media</i>						2		4	
<i>Silene alba</i>						1			
<i>Taraxacum officinale</i> agg.									
<i>Trifolium repens</i>						2			
<i>Trifolium pratense</i>						1			
<i>Tragopogon pratensis</i> agg.									
<i>Veronica chamaedrys</i>			2			2			
<i>Vicia cracca</i>			2			3			4
Grasses	32	48	31	57	66	18	36	52	21
Diversity	3.36	3.03	8.79	2.82	2.07	11.48	2.11	2.58	8.28

Fig. 11. Diversity (Simpson's index,) of plant species found on Brodsworth Tip.
Grasses counted as separate species.

	East	Top	West
Jun 94	6.28	5.96	15
Jun 95	6	4.21	15.57
Jun 96	6.23	5.54	10.65

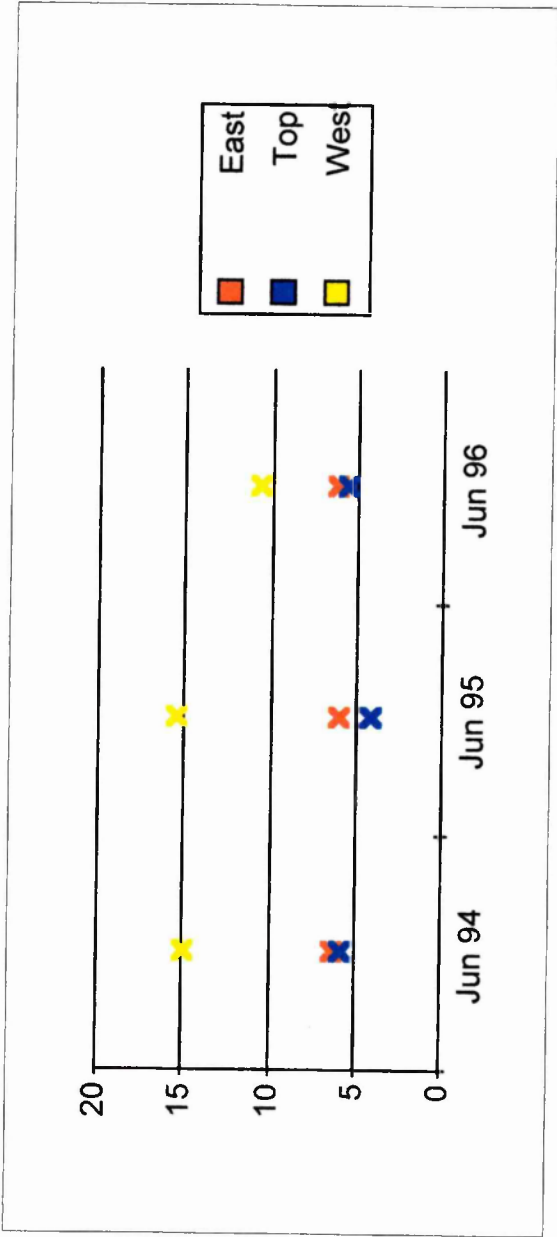


Fig. 12. Diversity (Simpson's index,) of plant species on Brodsworth Tip.
Grasses counted as a single species.

	East	Top	West
Jun 94	3.36	3.03	8.97
Mar 95	2.24	1.95	5.48
Apr 95	3.04	2.37	6.44
May 95	3.22	1.84	9.82
Jun 95	2.82	2.07	11.47
Apr 96	2.78	2.51	5.97
May 96	3.39	3.01	7.28
Jun 96	2.11	2.58	8.28

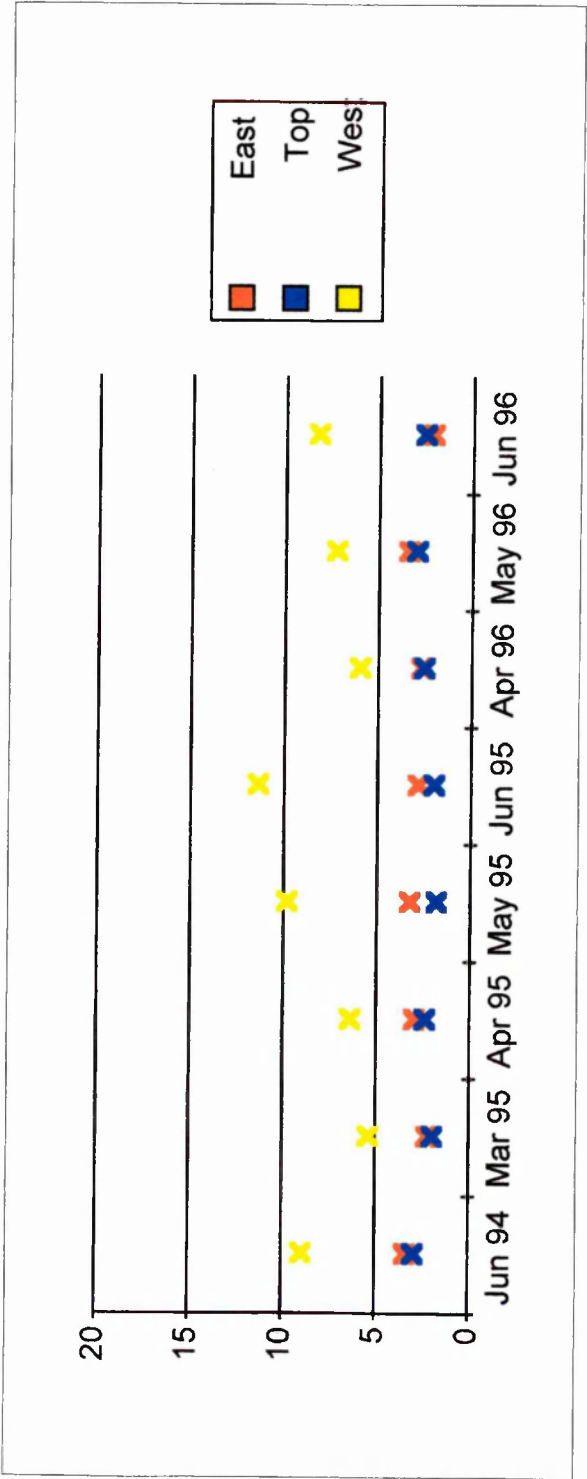
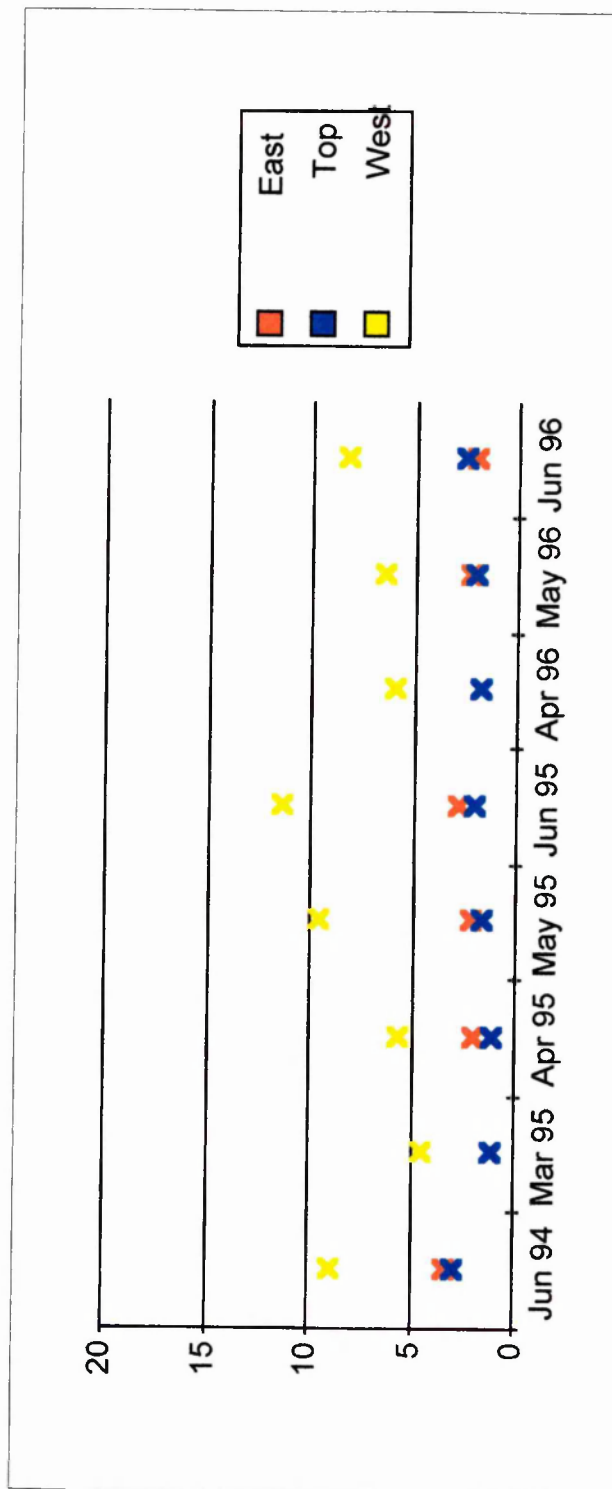


Fig. 13. Diversity (Simpson's index,) of plant species on Brodsworth Tip.
(Figures for bare ground and litter omitted.)

	East	Top	Wes
Jun 94	3.36	3.03	8.97
Mar 95	1.22	1.22	4.52
Apr 95	2.05	1.16	5.68
May 95	2.24	1.73	9.62
Jun 95	2.82	2.07	11.48
Apr 96	1.8	1.87	5.92
May 96	2.3	2.02	6.43
Jun 96	2.11	2.58	8.28



on the top and east end. The diversity shown in June 1995 for the west end, appears to be anomalous related to 1994 and 1996, but this was possibly due to the above average temperatures following a wet winter, resulting in greater production both in plant size and variety.

Diversity during the months of June 1994 and June 1995 are similar for the west and the east ends. There appears from these results to be slightly less diversity in the second June than in the earlier one as regards the top of the tip. However in all months results showed a broadly similar ratio between the west end and the other two areas. In 1994 there was marginally greater diversity at the east end than the top which was still apparent throughout the year until June 1995. In the early spring months it was not possible to identify grasses separately which reduced the calculated diversity.

In each month when the counts were made, the diversity index for the east was slightly higher than the top. Both of these parts showed much less diversity than the west end, where it appears that importation of soil enhanced plant growth. The greater diversity at the east end may be due to that part of the tip being older. The east end also had patches of cinders below the humus layer which reduced compaction and improved the drainage, in contrast with the top part which had more clay. (see soil analyses, **Table iii.**). It is possible that the cinders might prevent capillary upcreep of H_2SO_4 .

In the months, June in 1994, 1995 and 1996, when it was possible to separate the grasses into different species, then more consistent results were achieved. The greater diversity of species at the made up west end, contrasting with the true tip probably relates to the differences in soil quality, especially pH. (see soil section, Chapter 4, **Page 44**).

When all the grasses were grouped together (**Fig. 11**), and litter and bare patches were included, diversity increased in all parts of the tip from spring to summer. On the true tip, diversity changed from a mean figure of 2.01 to 2.92. In contrast, at the west end the diversity changed from 4.5 to a mean of 10.07 over the same period.

When the grasses were recorded as separate species in summer (**Fig 12**), the main tip shows a mean diversity of 6.22, while the west end has a diversity more than twice this, 13.71.

From these results it is seen that:

1. At all times greater diversity was shown at the west end than on the rest of the tip.
2. During spring months the diversity of plants on the east and top parts of the tip increased little.
3. During the spring months the diversity of plants on the west end increased by a factor of almost 2.

Also there were similar species of grasses on all parts of the tip, however grasses were more evident on the top and east end of the tip where there appeared to be less competition from other species.

5.1.4. Discussion.

These results reflect the differences in soil quality demonstrated in the soil analysis section of this work, and to a lesser extent, the different stages of succession reached by the youngest and oldest parts of the true tip. The difference between the two parts of the tip proper could be due to age, the east end was the beginning of tipping and is perhaps 20 years older than the top (about 90 years compared with about 70 years). An alternative view could be that the bare parts of the top were caused by

spontaneous (or deliberately started), combustion at a later date, limiting the variety of species found on that part. The increase in the occurrence of *Epilobium angustifolium*, (Rosebay willowherb,) close to the bare parts would support this suggestion.

Down (1975) quoting Brierley (1956), suggests that *Chamaenerion angustifolium*, (*Epilobium angustifolium* in The Wild Flowers of Britain and Northern Europe - Fitter *et al*, 1974), '...colonised near deep seated rocks though this might have been a response to moisture.'

Epilobium angustifolium is an early pioneer after land has been affected by fire, perhaps due to the availability of released potash. Down does not mention the possibility of spontaneous combustion during the 55 or 98 years life of the Somerset tips which he studied.

It has been difficult to find authors who have used Simpson's Index when measuring diversity. Either diversity has not been mentioned or an alternative system such as the Shannon - Wiener function has been used.

In order to overcome this problem, the Simpson index has been calculated for the results of other researchers' lists of point transects in woodland or limestone areas (see **Table viii**, page 83).

Table viii. Simpson's diversity index used on results of other researchers.

Source	Index
Woodland at Calver, (Piggot & Taylor 1964.)	6.67
Cressbrook Dale woods "	5.3
Brodsworth Hall, unkempt lawn	
Magnesian Limestone (Howes 1992) a	16.18
" " "	b 10.83
" " "	c 15.09
Lathkill Dale, Carboniferous Limestone (Allison 1982).	27.1

The results from the west end of the tip in June, up to a diversity of 15 (**Fig 12**), are very similar to those found by Howes at Brodsworth Hall. Neither Brodsworth Hall nor Brodsworth Colliery tip west end could compare with the results from those of Allison who worked on Carboniferous Limestone.

The diversity in the wooded parts of the top and east end of the tip, between 5 and 8 (**Fig 12**), compare well with the results of Piggot and Taylor's woodland studies in Derbyshire.

5.2.1. Belt Transect.

A belt transect was carried out over the whole length of the allocated tip in June 1994.

5.2.2. Method.

The survey started at the eastern, oldest, end of the tip. A 50cm x 50cm quadrat was used sub-divided into 25 smaller squares. The quadrat was dropped at measured 10 metre intervals using a line to make as straight a course as possible. Trees and bushes prevented the execution of a perfectly straight line. Results from a total of 26 quadrats were recorded. The tip is 250 m in length according to the map (**Fig. 8, Page 45**). The last quadrat reading was 2 m from the bottom of the western slope. At

each reading the dominant species of plant present in each of the 25 smaller squares was recorded.

5.2.3. Results.

The distribution of plants along the belt is illustrated **Fig 14, Page 85**. This exercise was not intended to provide a complete description of the site, rather an illustration of the general distribution of plant species over the tip.

5.2.4. Species frequency.

The species frequency and abundance were calculated by the methods used by Cadogan & Sutton (1994):

Species frequency.

$$\text{Frequency \%} = \frac{\text{No of quadrats containing a species}}{\text{Total no of quadrats}} \times 100$$

5.2.5. Species abundance.

The species abundance was calculated by counting the squares completely covered by a particular species:

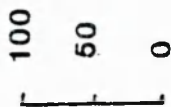
$$\text{Abundance \%} = \frac{\text{No of squares covered by a species}}{\text{Total no of squares}} \times 100$$

It will be noticed that the grass species are grouped together for the purposes of this exercise, grasses are examined separately in part of Simpson's Index.

5.2.6 Results.

Table ix. Page 86, shows the results for frequency and abundance.

Vertical scale % Cover



VEGETATION: BELT TRANSECT

Fig. 14.

W <-----> E

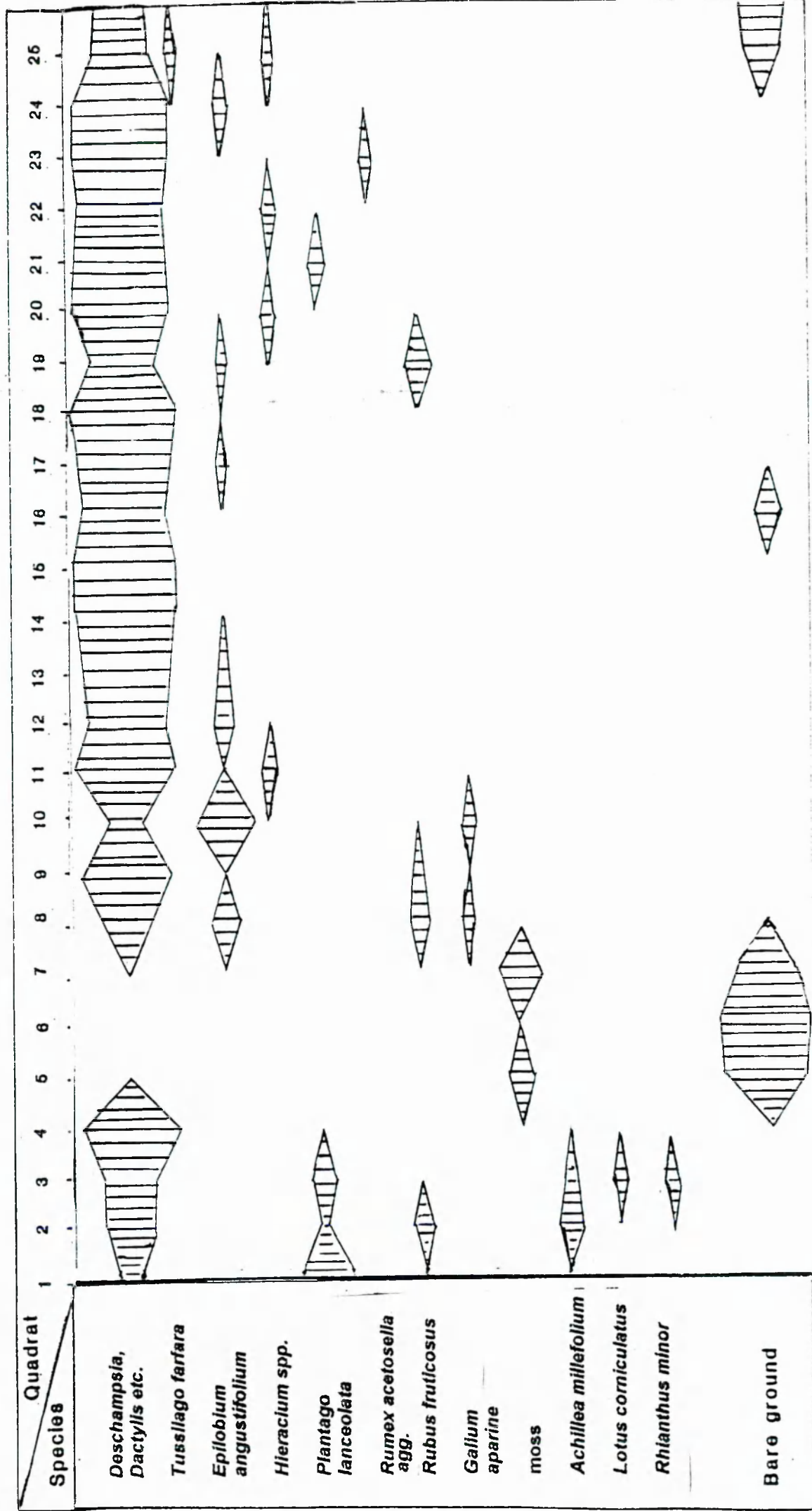


Table v. Frequency and Abundance of plants on Brodsworth Tip.

Species	Frequency%	Abundance %
Grasses	88.46	69.23
<i>Tussilago farfara</i>	3.85	0.15
<i>Epilobium angustifolium</i>	26.92	4.92
<i>Hieracium spp</i>	15.38	1.08
<i>Plantago lanceolata</i>	15.38	3.69
<i>Rumex acetosella</i>	3.85	0.15
<i>Rubus fruticosus agg.</i>	15.38	2.31
<i>Galium aparine</i>	7.69	0.31
Moss	7.69	2.15
<i>Achillea millefolium</i>	11.54	2.00
<i>Lotus corniculatus</i>	3.85	0.31
<i>Rhinanthus minor</i>	3.85	0.15
Bare ground	26.92	13.54

5.2.7 Discussion.

The Simpson index showed a much greater diversity of plants in the herb and shrub layer on the western (made-up), end of the tip than the rest of the tip. The older end showed a slightly greater diversity than the youngest part of the true tip. The plant cover found on the belt transect showed a sudden change in species found as the soil changed towards the western end.

The belt transect showed that of the area surveyed 13.5% of the spoil heap at Brodsworth was bare of vegetation while 69% was covered in grasses. The two most frequent herbs were *Epilobium angustifolium* Rosebay Willowherb, with 4.9% cover and *Plantago lanceolata*, Plantain, with 3.7% cover. *Rubus fruticosus agg.*, Bramble, was the most frequent shrub with 2.3% cover.

This compares with Chadwick and Hardiman (1976), who surveyed 22 colliery spoil heaps, where *Epilobium angustifolium*, Rosebay Willowherb, and *Tussilago farfara*, Coltsfoot, were the two most common herbs, while *Plantago lanceolata*, Plantain was 18th.

Richardson *et al* (1971), recording occurrences of plants on 237 pit heaps in County Durham again found *Epilobium angustifolium*, Rosebay Willowherb, most common with *Hieracium pilosella* (= *Pilosella officinalis*), Hawkweed, second and *Plantago lanceolata*, Plantain, seventh.

Of the trees, while *Betula pendula*, Silver Birch, was clearly most common at Brodsworth, Chadwick and Hardiman (op cit), found *Betula pendula*, second to *Quercus robur*, Common Oak, and Richardson found *Betula pendula* second to *Rubus fruticosus* agg, Bramble.

Grasses at Brodsworth were mainly *Poa pratensis*, Meadow Grass, and *Dactylis glomerata*, Cocksfoot, on the true tip, with *Deschampsia flexuosa*, Wavy Hair Grass, being most common on the made up west end.

Chadwick and Hardiman (op cit,) found *Agrostis capilaris*, Common Bent, more common than *Dactylis glomerata*, and *Deschampsia flexuosa*, fourth after *Holcus lanatus*, Yorkshire Fog. Richardson, on the other hand, found *Deschampsia flexuosa* and *Dactylis glomerata* most common.

Richards *et al* (1996), list six grasses frequently found on colliery spoil heaps, from a survey of 15 sites. These were, *Deschampsia flexuosa*, Wavy Hair Grass, *Holcus lanatus*, Yorkshire Fog, *Agrostis capilaris*, Common Bent, *Dactylis glomerata*, Cocksfoot, *Poa pratensis*, Meadow Grass, and *Festuca* spp. Fescues. All were found at Brodsworth.

The two commonest shrubs in their list were *Rubus fruticosus* agg. (Bramble), which was frequently found at Brodsworth, and *Ulex europaeus* (Gorse), which was absent. No *Ulex europaeus* (Gorse), has been noticed in the locality to provide a seed bank. While the seven commonest herbs noted by Chadwick and Hardiman (1976), Richardson *et al* (1976), and Richards *et al* (1996), were all found, *Tussilago farfara* (Coltsfoot), was found only at the edge of the oldest part of the tip, and *Lotus corniculatus* (Birdsfoot Trefoil), was found only on the western, lime-affected part.

The plants marked as calcicoles (Fitter *et al* 1974), in the list of species found at the western end of Brodsworth tip, indicate that the soil and the plant community found at that end are very different from the rest of the tip. As shown by the soil analysis the pH at the western end is much higher than at the east end or on the top, and is more like the local Magnesian Limestone rich soil. The surrounding hedgerows and motorway embankments provide a seed source of a wide assortment of plants including calcicoles which have become established at the western end.

Jeff Lunn, English Nature (pers. comm), supported the evidence of a richer limestone community adjoining the tip, towards the motorway embankment when he visited the site in September 1996. The diversity of plants found at the west end of the tip is almost as large as that found by Colin Howes, Doncaster Museum (pers. comm), on the unkempt lawns at Brodsworth Hall, which is one mile to the West of the tip. In contrast, the rest of the tip has a flora which is typical of the sort found by other authors mentioned in this chapter, Chadwick and Hardiman (1976), Richardson *et al* (1976), and Richards *et al* (1996).

The *Quercus robur*, Oak, present at the east end suggests that that end is approaching a climax vegetation before the younger top, of the tip.

Chapter 6.

Earthworm investigations at Brodsworth.

6.1.1 Background.

While spoil was being tipped, any earthworm populations present in the soil would have been compressed and destroyed, as described by Scullion (1984) . The north, east and south sides would also have been made inhospitable to earthworms, by the railway sidings, the pit head, and more tipping respectively, so any earthworms present as the pit developed would have been destroyed. Only the western end would have presented an available route for the immigration of earthworms, and this would have been unlikely to occur until a food source was available. Unweathered shales would have provided no nutrient until some plant material was present, even though the neutral, surface pH would be acceptable to earthworms.

Successful regeneration of earthworm populations on opencast sites, which have become earthworm-poor due to compaction and grading operations of topsoil, has been recorded by Stewart *et al* (1988). These physical activities have not altered the chemical or biological properties to such an extent that earthworms cannot re-establish themselves once reintroduced.

In contrast, deep mined colliery spoil is not physically, chemically or biologically suitable for earthworms. Freshly dumped shale has a neutral pH but the particle size is large and there is no food source. As the shales weather to clays and some plant species are able to gain root hold, some species of earthworm might find enough food to breed successfully. One would expect these processes to take an inordinately long time, particularly considering the lowering of pH due to decomposition of pyrite.

6.1.2. Testing the Method used in Earthworm Surveys.

Raw (1959), provided a method of inducing earthworms to emerge at the surface of soil which has been widely used by researchers since its publication.

Unfortunately his method depends on the use of formalin which has subsequently been found to be carcinogenic. This raises serious problems when the substance is used particularly by young students. Schools have been encouraged to use a detergent solution; Slingsby and Cook (1986), suggest 10cm³ detergent in 2 litres of water producing a 5% solution, but this is of dubious efficiency.

In this work sodium hypochlorite has been used with a dilution formula which is recommended for its convenience. A 35mm film container is a convenient measure (35ml) to be made up to 1,000ml with water =1750ppm.

Two one litre applications of this solution on a quadrat of area 0.25m² with a 15 minute wait between the two will encourage worms to surface. A third application does not yield any more. If the worms are rinsed in clean water immediately after surfacing they appear to suffer no lasting effects and can be returned to the soil or retained for observation in a container of soil.

Very dilute solutions of sodium hypochlorite solutions have been used successfully. Sodium hypochlorite is present in known strength 2% + Na Cl in the commercial preparation for cleaning infant feeding bottles called MILTON, and in mild household bleaches, eg TESCO's product is <5%.

This method was successfully used by a group of 'A' level pupils when comparing worm populations as the practical element of their examination coursework in 1994 (Edlington School, Doncaster, 1994.)

This technique has worked with positive results both on pilot experiments on a garden lawn and in the field.

6.1.3. Pilot trial, Method.

In order that the accuracy of the technique could be assessed, eight random locations for hand sorting, and eight random locations for the bleach method were plotted in a lawn.

Quadrats each 0.5m x 0.5m were excavated to a depth of 0.2m. The soil was sieved (5mm sieve) and earthworms picked out. The turf was teased apart and then passed through the sieve. Checks were made on the soil below 0.2m by using bleach solution on the bottom of the hole but no worms surfaced. The process was time consuming, each hole taking up to 2 hours to complete, compared with 20-30 minutes waiting time for the bleach solution method.

The same size quadrats were used for bleach extraction and treated with 1000 ml solution as described above and worms removed as they surfaced. The method was then repeated. Worms were rinsed with clean water and placed in a plastic container for subsequent counting. Most of the worms were either *Lumbricus terrestris* or *Aporrectodea longa*.

Because of the time necessary to complete each excavation, the experiment took several days to complete.

6.14. Results, see Table x.

Table x. Numbers of worms found in a lawn by handsorting and bleach extracting. (May 1995).				
	samples	mean	sd	se
hand	8	116	26.15	9.25
bleach	8	74.5	21.35	7.55

Using the Mann-Whitney U Test, it was shown that there was a significant difference between the two methods of counting earthworms, $P<0.05$.

6.1.5. Discussion.

Bleach extracting seemingly accounted for 64.2% of the worms found by hand sorting. Taking the latter as the actual number present suggests that a multiple of 1.5 would give the approximate numbers from the bleach data on that soil.

As the weather became dry at the end of the first handsorting method, (the lawn was on sand,) it was necessary to postpone the bleach method until October when it was moist enough for earthworm activity to resume. Seasonal variation in worm population is quite likely to occur, so the trial was repeated the following year.

6.1.6. Repeat trial, Method.

The verification exercise was repeated in May 1996. Plots were dug in cultivated sandy soil, while bleach was applied to other plots as described above. Fewer worms were found, and the bleach system yielded less than 50% of the total found by handsorting.

6.17. Results, see Table xi.

Table xi. Numbers of worms found in cultivated garden by hand sorting and bleach extraction. (May 1996.)				
	samples	mean	sd	se
hand	4	67	10.2	5.1
bleach	5	28.8	6.88	3.1

In this case bleach extraction appeared to produce 43% of the worms found by hand sorting. Again, using the Mann-Whitney U Test, it was shown that there was a significant difference between the two methods of counting earthworms, $P<0.05$.

It was also shown, using the Mann-Whitney U Test, that there was a significant difference between the numbers of earthworms present in the lawn and in the cultivated garden, $P < 0.05$.

6.1.8. Discussion.

These greatly differing results suggest that a further attempt at verifying the bleach method should be attempted, in soil which is known to contain large numbers of worms. The texture of sand is different to that of colliery spoil, so repeating the procedure on spoil might be necessary, however time was not available to complete this further exercise. It might also be advantageous to carry out further trials of the bleach method on different types of soil on land known to be well populated with earthworms, to establish the efficiency of the method.

6.2.1 Surveying the tip.

Four areas were selected on the tip:

Site A - The vegetated highest part of the tip.

Site AA - The unvegetated high part of the tip.

Site B - The youngest western end of the tip, (topped with local soil).

Site C - The eastern oldest end of the tip.

See map, (Fig. 8, Page 45.)

6.2.2. Method.

The first random quadrats were made on sites A, AA, & C, in Nov 1993, and Mar 1994, using the bleach method described above to encourage earthworms to surface. The ones on B were not completed until Oct 1994.

6.2.3.Results:

See Table xii.

Table xii. Numbers of worms found at Brodsworth tip.

year	plot	samples	mean	median	se
93/94	A (top)	10	31.4	29	2.9
93/94	AA(bare)	4	0		
93/94	B(west)	6	27.3	16	9.3
93/94	C(east)	10	11.6	14	2.5
95	A (Top)	6	0		
95	AA(bare)	2	0		
95	B(west)	4	0		
95	C(east)	6	2	2	0.76
96	A(top)	9	21.77	24	3.9
96	B(west)	6	14	14	3.1
96	C(east)	9	16.88	16	2.7

Species found included, *Lumbricus rubellus*, occasional examples of *Lumbricus terrestris*, three *Aporrectodea longa*, (at the west end), and a single *Octolasion cyaneum*. The median numbers in plots A and C were significantly different, $P < 0.05$, using the Mann-Whitney U Test in the 1993/4 trials.

6.24. Conclusions.

Repeated counts, in 1966, appear to confirm that there were differences between the earthworm populations at the top of the tip and the east end, but that they were not significantly different, ($p < 0.05$). It is concluded that over the whole of the original tip under consideration, migration of worms is taking place from the nearby soil.

Migration probably takes place on the surface at night, preferably in humid conditions. *Lumbricus terrestris* (called the Night Crawler in America,) was noted to be active away from burrows by Darwin, (1881). Mather & Christensen (1988,) recorded earthworm trails up to 19.3m long. Again, Mather & Christensen (1992,)

recorded 857 individuals from 10 species of earthworm migrating during 20 minute periods over 28 nights. They concluded that surface migration is an important component of the behaviour of many earthworm species.

6.25. Discussion.

A fair criticism of the first results is that the tests were not performed within a short space of time. Weather and seasonal changes would be expected to influence the results. The initial tests covered November 1993 to May 1994. Trials carried out in 1995 were deemed meaningless due to prolonged drought. The second meaningful counts were carried out during late April/early May 1996.

Worm counts on the west slope were considered unreliable as the steep slope caused the testing solution to run along the surface rather than sink into the soil. Differences in the rate of absorption will also be found between dry and wet conditions. Again solution applied on the east end of the tip where cinders might be present, is likely to penetrate further than into the heavier clay on the top of the tip. Perhaps increased application of solution to ensure complete wetting is the answer for an area of varied texture as found on colliery spoil.

The worm community does not appear to be correlated with either soil conditions or plant populations on the tip, provided some vegetation is present. Despite repeated tests carried out during 1993, 94 and 95, there was no evidence of worm presence in the bare parts. The worm populations as found on the tip were low compared with counts from most other areas. See **Table xiii**.

Table xiii. Comparison of various worm surveys.

Source	number of worms (m ²)
East end of tip (1994)	11.6
Top of tip "	31.4
West end of tip "	28
East end of tip (1996)	16.88
Top of tip "	21.77
West end of tip "	14
Lawn (See above)	74.5
Cultivated garden (above)	44.64
Established Birch 38 years.(Miles 1981)	127
Mull (Lofty 1974)	500
Arable orchard (Raw 1959) using formalin	444
" " " handsorting	127.8
Derbyshire, 8 restored opencast sites using formalin.	
(Armstrong & Bragg,1984)	120 - 202
Durham, 4 opencast sites using formalin.	
(Armstrong & Bragg,1984)	89 -282
South Wales, 5 opencast sites using formalin.	
(Armstrong & Bragg,1984)	6 -39

The wide range of earthworm numbers in the table above is due to many reasons, some of which are suggested here.

Lofty (1974,) was working in a very favourable situation, in a rich mull soil which would be expected to support many earthworms .

Raw's (1959) figures have been derived from numbers per 4 square feet, again his soil was of good quality although cultivation of the land reduced the numbers of worms. When Raw hand sorted, he dug to a depth of 8 inches (20.3 cm). Raw

also found fewer worms by hand sorting than by using formalin, perhaps due to worms moving deeper than 8 inches during the hand sorting.

The lawn used to obtain the correction factor was on sandy soil which included some rubble underneath. The topsoil was thin. In addition the lawn is mown with the box on the mower, and lawn feed including weed killing chemicals had been applied in earlier years. The lack of humus resulting from the structure of the subsoil and the lawn's treatment would not encourage a large number of earthworms. Similarly as the cultivated garden was regularly hoed, the continual disturbance would discourage earthworms.

The east end of the tip is furthest from established soil so migration will take a longer time. On the west end of the tip where the soil has neutral pH, the steep slope makes accurate worm counting difficult due to solutions used to encourage worms to surface, running off and failing to penetrate far into the spoil.

Soil depth is small on all parts of the tip limiting the earthworm populations in such a habitat. In some parts the soil has been noted as being so thin above the heavy clay that no earthworms are found at all.

Given the possibility that enhanced worm numbers would improve soil formation, it would be worthwhile investigating methods for increasing worm numbers. If nutrients for earthworms could be introduced plus a rapidly reproducing earthworm species, then soil conditions could be improved. These conditions would enable species of deeper burrowing worms to be introduced to the improved soil to work at greater depth aerating the soil in a shorter length of time.

Chapter 7.

Culturing worms in controlled conditions.

7.1.1. Introduction.

The results from observations at Brodsworth showed that worms can and do migrate to colliery spoil when conditions are favourable. The questions to be answered were:

To what extent do worms ameliorate colliery spoil?

If worms were found to ameliorate spoil to an appreciable extent, what conditions are the most favourable for worms to be active?

Keeping numbers of earthworms in suitable conditions for observation over a long period was in itself a design problem. The traditional wormery used in schools restricts free movement of the occupants due to its narrow design and was therefore dismissed. To give unrestricted movement in a container such as a tea chest poses practical difficulties of handling and observing. A convenient size was 4 - 5 litres, and it was decided to perform pilot experiments in containers which would hold this amount of soil.

The overall shape of the container was the next problem to be addressed. Some species of worm would habitually try to burrow deeply so a narrow cylinder would be convenient. A piece of plastic drainpipe would provide suitable dimensions for that amount of soil, but would not permit observation of progress within it.

Two pieces of guttering held together by strips of plastic adhesive tape of industrial quality (British Gas specification PRS 10, available from builders' merchants), was found to be strong enough to hold the container together. If the cylinder is laid on its side and one piece of tape removed, then the upper half of the cylinder can be

raised, hinged by the second tape. The contents can then be viewed, and the tape reused.

The problems of drainage and aeration of the soil was overcome by covering the bottom of the cylinder with perforated polythene. While this works well there are problems of sticking the polythene to the cylinder, removing it for inspection and then replacing the polythene undamaged and clean with the tape. While an individual can cope with this inconvenience, a perforated hard cover to fit over the end is envisaged for further investigations. The cylinder was stood in a plastic plant pot within a second plastic container.

(See Fig. 15, Page 100).

A second cover, as described above, would be advantageous for the top of the cylinder to prevent the possible escape of some worms which are able to adhere to the vertical wall of the cylinder and climb to the top. Inverted plant pots, or perforated polythene bags, have been used but escapes have been made through the top.

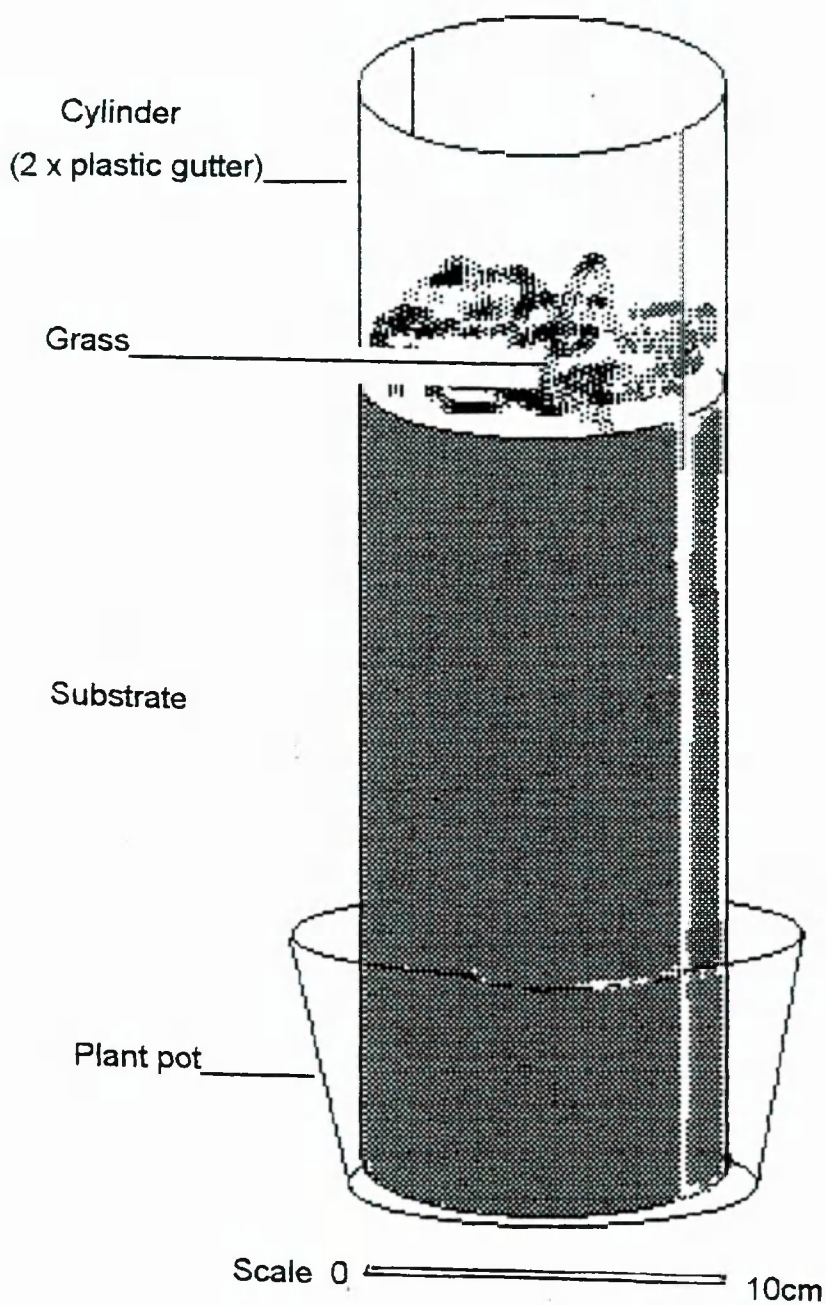
This system worked well in its prototype form for all experiments up to the end of 1994, and worms survived in sand with grass without signs of distress for weeks or months at a time.

7.1.2. Pilot Experiment (Expt. 1).

A trial wormery set was up with 5 litres of smooth building sand in a cylinder made of two pieces of plastic guttering bound with tape. Building sand was used because:

Sand was cheap and readily available.

Sand had a neutral pH.



PROTOTYPE WORMERY

Fig. 15. Prototype wormery, large enough for 10+ worms. (1.6l approx).

Smooth sand would not be an irritant to the earthworm's skin.

Sand was free of plant or animal remains so that food could be added and measured accurately.

Sand enabled the earthworm's progress to be seen easily.

7.1.3. Method.

The ends were covered with perforated polythene. Ten worms were introduced from a lawn, 5 *Lumbricus terrestris* and 5 *Aporrectodea longa*. Grass mowings were provided on top as a supply of nourishment, and water was added occasionally. The cylinders were kept in a garage, and the maximum air temperature ranged from 23-16°C, and the minimum air temperature ranged from 17-1°C.

7.1.4. Results.

Photographs were taken at:

7 days	Some evidence of tunnelling by worms noticed.
18 days	Activity noticed throughout observation time.
32 days	Colour change to darker brown around burrows.
59 days	Sand adhered to plastic, particularly dark sand.

Tracings were made of the photographs. The tracings were transferred to graph paper, and the proportion of worked sand counted as a percentage of the total area seen. (It was considered that the area observed would accurately reflect the volume which was actually worked.)

(See Plates XIII, XIV, XV & XVI, Pages 102 & 103.)



Plate XIV. Worm action in sand cylinder after 18 days.



Plate XIII. Worm action in sand cylinder after 7 days.



Plate XVI. Worm action in sand cylinder after 59 days.

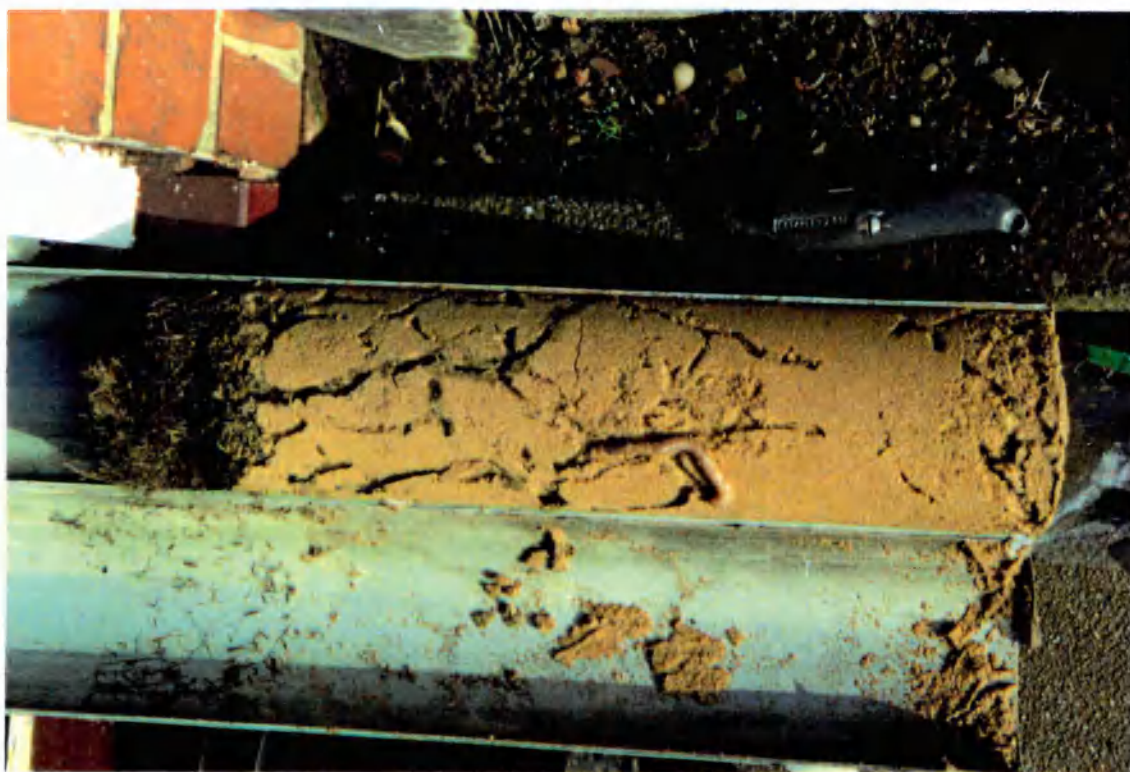


Plate XVII. Worm action in sand cylinder after 59 days.

The Percentage figures were plotted against time (in days), and a linear regression line was drawn (see **Fig. 16, Page 105**). From the graph, the time for half the sand to be worked was 82 days.

When the cylinder was emptied after 40 weeks, 8 worms were present. The sand was darker throughout and adhered readily to the plastic of the cylinder.

7.1.6. Conclusions.

Samples of worms taken at random from a lawn survived reasonably well in the experimental conditions, using sand as a substrate. Over a period of 40 weeks (nine months), only two worms were lost out of ten. (20%).

From the graph, the time for half the sand to be worked was 82 days. (1 litre in 41 days). It could be argued that the worm movement is somewhat random and parts of the substrate will be reworked while other parts might not be touched by the burrowing worms. As time passes, more soil will be reworked, while less new soil will be opened up, resulting in a curved graph. An exponential curve resulting from the amount of soil worked might be drawn although the amount of data is small. The experiment is worthy of repeating in order to deduce a work rate for worms in sand.

The following experiments were selected to find if a common worm species is able to work colliery spoil. Repeating the experiment with weathered shale would pose difficulties in photographing burrows which would be difficult to see and hence measure. Besides the possibility of earthworms working spoil to alter its condition, any breeding while in the spoil would be taken as an indication of successful colonisation by earthworms.

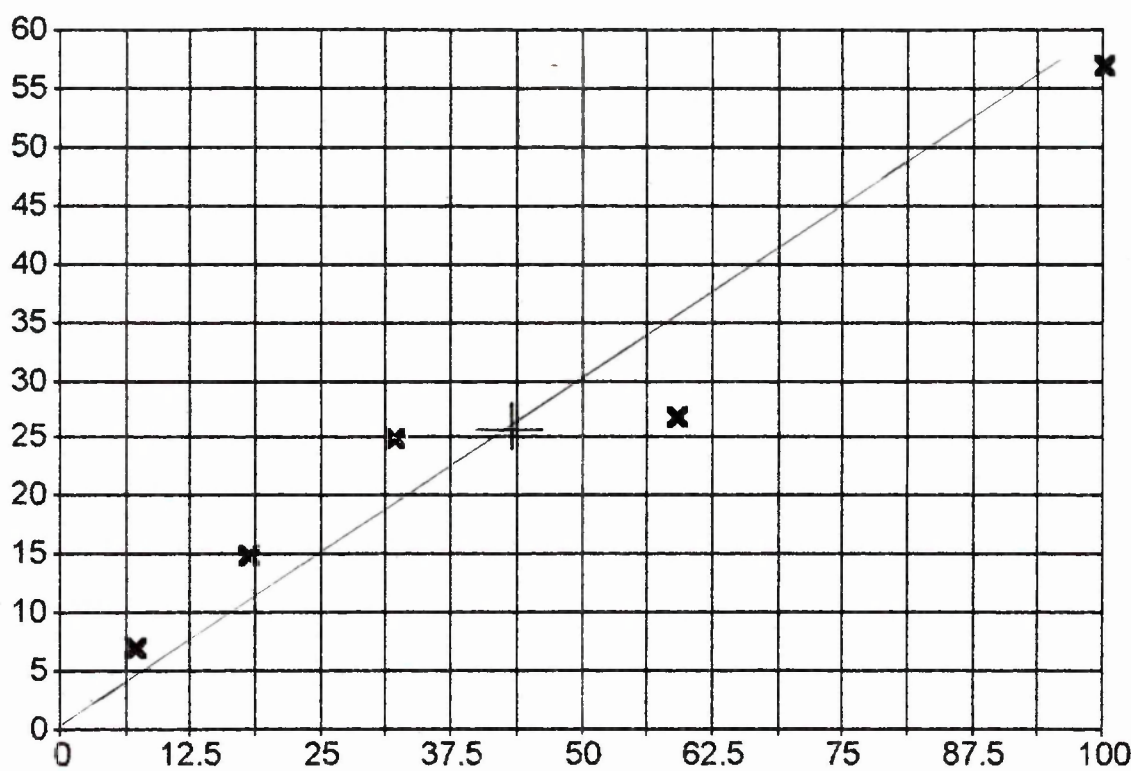


Fig. 16. result of 10 earthworms, (*Lumbricus terrestris* & *Aporrectodea longa*), working in 5 litres of sand.
X axis = time (days).
Y axis = % sand worked.

7.2.1. Comparing earthworm species (Expt.2.)

As a supply of *Eisenia fetida* was available from a vermicompost bin, a comparison with the larger species *Lumbricus terrestris* and *Aporrectodea longa* was possible.

7.2.2. Method.

Two cylinders were set up as described above, using a substrate of spoil taken from the bare area of the top of the tip described earlier. A mixture of *Lumbricus terrestris* and *Aporrectodea longa* was placed in one cylinder and *Eisenia fetida* in the other. Both groups of earthworms and the feed were weighed before and after the experiment. The cylinders were left for 98 days in a mean air temperature ranging from 18°C to 9°C.

7.2.3. Results.

The results are shown in Table xiv.

Table xiv. Result of comparing the progress of worm species in sand.						
Species	no	g worms	g grass init	g grass fin	pH init	pH fin
<i>Eisenia fetida</i>	10	2.28	27.63	10.4	5.2	6.1
<i>Lumbricus terrestris</i> & <i>Aporrectodea longa</i>	14	13.37	83.1	44.42	5.2	5.7

Food consumed by *Eisenia fetida* was 1.72g/worm or 17.58g/mg/worm/day.
Food consumed by *Lumbricus terrestris* & *Aporrectodea longa* was 2.76g/worm or 28mg/worm/day.

The difference in food consumed is reversed however if the rate is calculated per gram of worm.

Food consumed by *Eisenia fetida* was 7.56g grass/g of worm.

Food consumed by *Lumbricus terrestris* & *Aporrectodea longa* was 2.89g grass/g of worm.

7.2.4. Conclusions.

The apparent relationship between size of earthworms and the amount of food that they consume could have a bearing on the species selected for further trials.

However, these results refer to fresh weights of grass, and as drying facilities were not available, this line of enquiry was suspended.

7.3.1. Investigating the effect of substrate, weathered spoil (Expt. 3).

When trials began using earthworms and spoil samples, the spoil structure presented some problems. In order to simulate the conditions encountered by earthworms on migrating to a tip, the samples used were taken from the bare parts of the tip where pH was lower than the vegetated parts and there was an absence of vascular plants and earthworms. The spoil was well packed, but on removal with a trowel became loosened into lumps of varying sizes. A direct comparison of the behaviour of *Eisenia fetida* in the different substrates was sought in this experiment.

7.3.2. Method.

It was not possible to repack the spoil into the cylinder. The spoil was put into the cylinders in the form of irregular lumps. Should the appropriate implements be available, then solid cores of spoil could be extracted and placed in cylinders with a close fit, to resemble more closely the field conditions.

A mixture of garden worms was used in early trials (see pilot experiment, Expt.1), but later *Eisenia fetida* was used when it was noticed that this species was able to move

below the surface of the mineral spoil and alter its texture. *Eisenia fetida* was also readily available from a vermicompost bin.

Three cylinders were set up as shown in the **Table xv** (the two spoil samples were from the same part of the tip). Wilted grass mowings were given as feed, with occasional watering, and left for 12 weeks. Weekly mean temperatures during the experiment ranged from 18°C to 10°C. After that time, the cylinders were examined and the results are shown in the same table.

7.3.3. Results.

Table xv. *Eisenia fetida* in cylinders for 12 weeks.

Species	substrate	no	survivors	initial pH	final pH	initial wt worms (g)	final wt worms(g)
<i>Eisenia fetida</i>	sand	10	8	7.0	6.6	2.75	2.77
<i>Eisenia fetida</i>	spoil1	10	7	5.1	5.8	2.87	2.17
<i>Eisenia fetida</i>	spoil2	10	6	5.1	5.7	2.86	1.55

When the loosened spoil was used in the cylinders, spaces between the lumps enabled worms to pass among them, and épigé species were found to go deeper than anticipated. The texture of the spoil was improved by the presence of the worms, being more crumbly than at the start of the experiment.

Plates XVII & XVIII, Page 109, show *Eisenia fetida* actively working on sand and spoil. *Eisenia fetida* are marked E.f and granulated particles G.



Plate XVII.
The sticky nature of sand worked by worms.

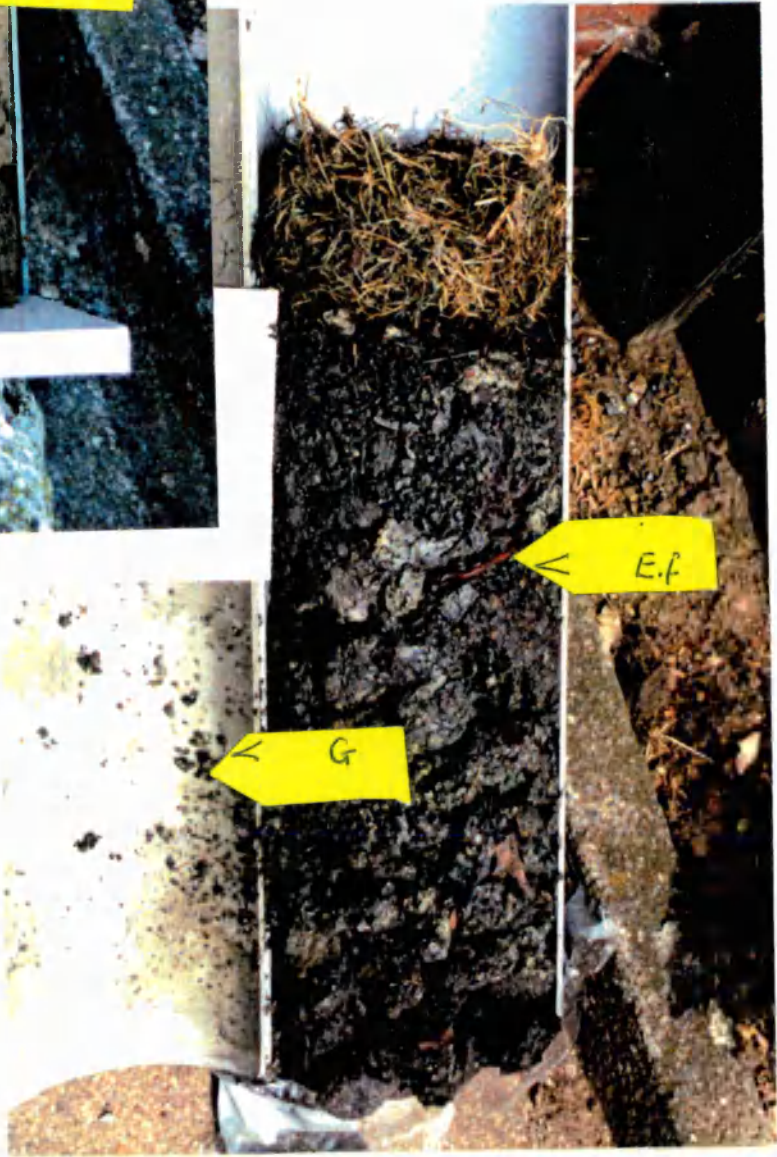


Plate XVIII.
The crumbly nature of spoil worked by worms.

There was a 20-40 % loss of worms in each of the cylinders. When the cylinders were opened all the worms present were noticeably active and were, without exception, found at the edge of the substrate. Three were found below the paper seal in spoil number 1. (Paper was used in this instance to prevent waterlogging when water was added). When the cylinders were reassembled, and the worms replaced on the top of the grass, one was seen to climb up on to the polythene bag sealing the top. It is presumed that losses may have been due to escapes.

Grass was seen to have been taken down into the substrate, and some was presumably consumed, as the surviving worms were very healthy and the total mass of worms in the case of the sand cylinder was greater at the end of the experiment than at the beginning despite the reduction in numbers.

The spoil had crumbly texture at the end of the experiment. Only a few large pieces of clay remained in cylinder 1. While in cylinder 2 the texture was also crumbly, more clay lumps remained.

A series of photographs were taken during the trial. Using a grid to measure the amount of burrowing in the sand which had taken place shown by the photographs, a graph was produced, see **Fig. 17, Page 111**. A regression line was calculated and drawn. 50% of the 1.6 Litres was worked in 54 days, (a rate of 1 litre in 67 days, compared with 1 litre in 33 days for the *Lumbricus terrestris*, *Aporrectodea longa* mixture).

A possible hyperbolic curve was also drawn by eye which showed that half the available sand was worked in 47 days.

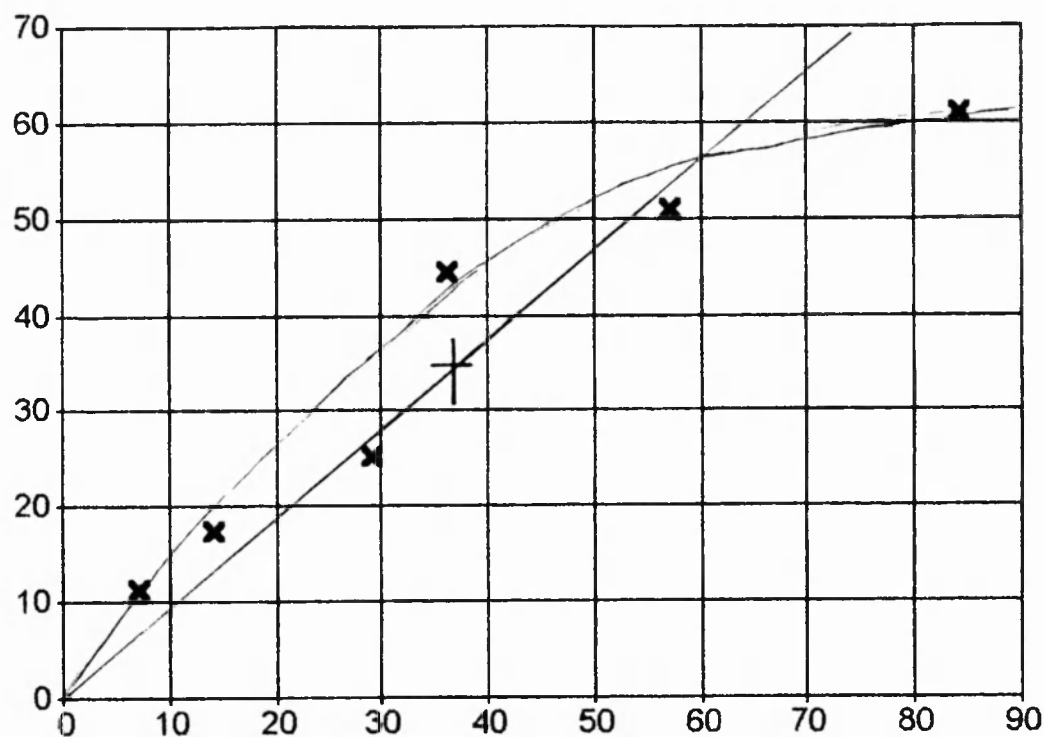


Fig. 17. Result of 10 earthworms, (*Eisenia fetida*), working in 1.6 litres of sand.
X axis = time (days).
Y axis = % sand worked.

The slower work rate compared with the mixture of *Lumbricus terrestris* and *Aporrectodea longa* is explained by the smaller size of *Eisenia fetida*.

7.3.5. Discussion.

The results indicate that *Eisenia fetida* may be a possible agent for beginning the improvement of colliery spoil towards becoming a useable soil. pH in the sand was lowered from 7 to 6.6 due to the introduction of decaying vegetable matter, which would slightly increase the acidity. No control experiment (without worms,) was carried out to verify this result. It was assumed that the lowering of pH was due to the formation of humic acid in the decomposition process and the release of carbon dioxide. (Killham 1994). In both the cylinders of spoil, the pH was raised from 5.1 to 5.7 or 5.8. The sample size is too small to state the significance of the change in pH, but the change is worthy of further investigation .

After a further six months the pH in the cylinder of spoil had lowered to 4.5. Some worms were alive but appeared to be less than in full health. The lowering of pH might be due to aeration. Because the spoil was loose, the pyrite was likely to be oxidised to sulphate, and sulphuric acid. (See the action of *Thiobacillus ferrooxidans* and *Thiobacillus thiooxidans* in the 'Interpretation of the results of soil analysis.' Chapter 4.)

The two surviving worms were small and both exuded yellow coelomic fluid immediately on being handled, suggesting stress. The remaining grass had become dry suggesting that the food source needs to be moist for successful work with *Eisenia fetida*, as is found in a vermicompost bin.

Although *Lumbricus terrestris* and *Aporrectodea longa* had shown a faster work rate, it was decided to limit the study to the effects of *Eisenia fetida* on spoil for three reasons:

Eisenia fetida can tolerate low pH (Sims & Gerard, 1985).

Eisenia fetida breeds more rapidly than the deeper burrowing *Lumbricus terrestris*, (Wallwork, 1983), and could thus be used to promote rapid, (though shallow), improvement of texture and pH before introducing *Lumbricus terrestris*.

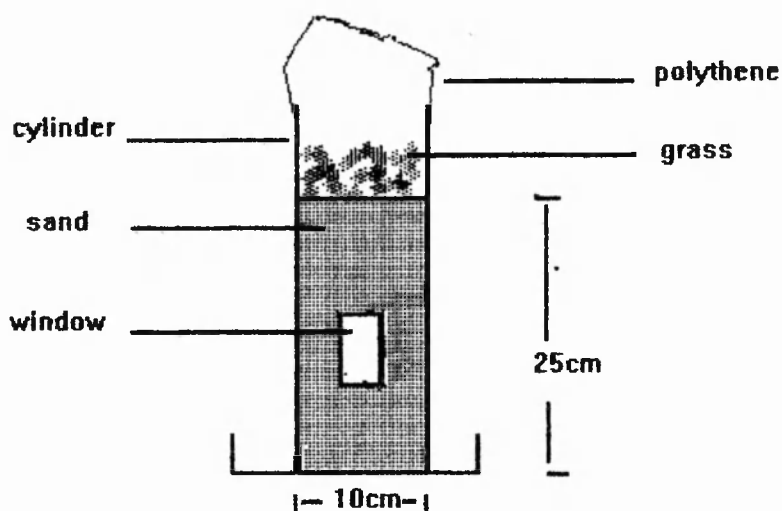
As noticed in the above trial, *Eisenia fetida* appeared to cause a raising of the pH of the spoil.

7.4.1. Repeat experiments to find rate of *E.fetida* working sand. (Expt. 4.)

7.4.2. Method.

The method used was as before except that cylinders used were redesigned with 5 x 10 cm window, which was covered to exclude light (see **Fig. 18, Page 115**). The purpose of the window was intended to enable observations of the worms to be made with minimum disturbance by avoiding removal of half of the cylinder. Sand to a depth of 25 cm (2 litres approx,) was placed in the two cylinders and water was added until moisture was noticed in the sand through the windows. Wilted grass was placed on top and ten worms were placed on top of the grass.

pH of sand 7.0.

Fig. 18. Redesigned cylinder.**7.4.3. Results.**

The results after 24 weeks are shown in **Table xvi.**

Table xvi. *E. fetida* in redesigned cylinder.

cylinder	pH initial	pH after 24 weeks	remarks
a	7.0	5.3	Burrows noticed
b	7.0	5.6	Burrows noticed, 12 Hatchlings.

After a further 50 weeks:

It was noticed that the window area had been avoided by the worms, so a record of the progress was not available by regular photographing the of windows as had been intended. No worms had survived the winter, when air temperatures had dropped to 0°C in the garage where the apparatus was kept, although a lot of grass had been

consumed. On sectioning the sand searching for worms, evidence of burrowing was noted.

7.5.1. An attempt to mimic field conditions. (Expt. 5.)

An attempt to mimic field conditions more closely was made using a starter culture of *Eisenia fetida* in polythene bags resembling the earthworm inoculation units (EIUs), used by Butt *et al* (1995) .

7.5.2. Method.

Two polythene bags of 2 litres approx. were used containing moist sand and grass, and a third bag containing colliery spoil and grass were set up with ventilation provided by perforated strips of polythene taped into the necks of the bags. Four mature worms were placed in each bag. The bags were kept in a dark cupboard in a garage throughout summer and winter when a range of temperatures was experienced. The minimum air temperature reached was 0°C during February, and the maximum temperature was 33°C in July.

7.5.3. Results.

After one year the EIUs were examined. Both bags containing sand and grass showed no signs of life although both were still moist. Despite the large range in temperature experienced, the bag containing spoil and grass was found to yield five hatchlings. These were removed and placed in an outdoor wormery under optimum conditions. The contents of the polythene bags were returned to a plastic bag and chopped carrot and potato were added to provide nourishment for any fresh hatchlings which might appear, should any cocoons remain in the mixture.

7.5.4. Discussion.

The success in breeding in this experiment, along with the success in the cylinders, suggests that with care, a similar method might be attempted in the field.

7.6.1. Repeat trials to check pH rise (Expt. 6).

7.6.2. Method.

In order to confirm earlier results, and to reduce the possibility of loss of worms by cold or escapes, four larger perspex cylinders were set up (diameter 13.8cm), each containing 10 *Eisenia fetida*. Spoil was placed in the cylinders to a depth of 10 - 15 cm. Dry grass mowings were placed in the cylinders as a food source for the worms, and as both spoil and grass were quite dry water was added.

Eight of the original type of cylinder were set up at the same time with spoil. Again the initial pH was 4.7. After the same time, the mean pH had risen to 5.5, \pm 0.37. The mean of rises in pH was 0.81, \pm 0.33.

7.6.3. Results.

After 40 weeks, the results were as shown in **Table xvii**.

Table xvii pH rise in worm colonies in perspex cylinders and Mk 1 cylinders.		
cylinders	initial pH	median of final pH
4	4.7	5.35 \pm 0.13
8	4.7	5.55 \pm 0.39

The median pH values after both the trials were significantly different from the starting pH, ($p < 0.05$), using the Mann-Whitney U Test.

7.6.4. Discussion.

This is a remarkable change in pH which formerly might have been presumed to be due to the action of the calciferous glands in *Eisenia fetida*. It is now known that such a situation is unlikely.

The pH of the gut in earthworms ranges between 6.3 and 7.3, which is in contrast to the likely acid tendency of plant material which is the source of food for worms (Killham 1994). *Lumbricus terrestris* and *Aporrectodea longa* secrete a proteolytic enzyme from their pharyngeal glands but *Eisenia fetida* does not, although an amylase has been shown to be present (van Gansen, 1962). The intestine is the main digestive and absorptive part of the gut, where among others protease, lipase, cellulase and amylase are present. Enzymes work better in a near neutral pH, but the secretions of the calciferous glands, situated after the oesophagus and before the crop, have been found to be resistant calcite granules (Wallwork 1983). Pearce (1972), suggests that these glands are more concerned with regulating pH in the coelomic fluid. Furthermore the calciferous glands of *Eisenia fetida*, a compost feeder, are simple and inactive as far as calcium metabolism is concerned.

A more likely source of a neutralising chemical is ammonia secreted into the intestine. Ammonia is produced by the passage of organic complexes through the digestive system of earthworms, where the action of enzymes breaks the large molecules into simpler ones releasing nitrogen in that form, along with nitrites and nitrates. This is most likely to occur where the plant tissue is from soft leaves with a high N to C ratio and a low level of phenols, (phenyl propane is the basic unit of lignin,) because soil animals do not possess phenolase, as do *Basidiomycotina* (Killham 1994).

Killham (1994), has questioned the source of the enzymes in the earthworm gut which effect comminution of plant detritus. He has drawn attention to the presence of

a large variety of gut microflora in earthworms including cellulolytic and other bacteria which are able to break down leaf litter. Worm casts have been shown to have a higher microbial density than unprocessed soil. He also points to the diversity of microbes in the gut being similar to that of soil suggesting that the microbes are used as food rather than agents for digesting food.

Chapter 8.

Examining the Effects of Feedstuff.

8.1.1. Measuring the amount of food consumed by 10 worms (*Eisenia fetida*).
(Expt. 7.)

This experiment follows the suspended **Expt. 2.** as an oven became available for recording dry weights.

8.1.2. Method.

Five samples of wilted grass were weighed, dried at 100°C, and reweighed until the weight was constant.

Ten worms were placed in each of six cylinders of moist sand with a weighed quantity of wilted grass as feed. After 35 days the grass was separated from the moist sand and worms, dried, then reweighed. The dry weights of the original feed were calculated and hence the amount of grass consumed in each cylinder.

In a similar manner, the experiment was also undertaken using nylon net bags, made from stockings, (mesh <1mm,) each containing 10 earthworms and grass placed on a bed of wet sand. Five bags were used, and the procedure was as outlined above.

8.1.3. Results.

The results are in **Table xviii.** The mean dry matter was 69.03% ± 1.8 of the original weight.

Table xviii. Feeding rate of *Eisenia fetida* over 30 days.

	mean dry wt consumed by each worm per day	mean wilted wt consumed by each worm per day
Cylinders	12.3mg	22.14mg
Net bags	14.13mg	25.44mg

8.1.4. Discussion.

The net bags probably produced the better result as sand may have been mixed with the grass (for the second weighing), leading to a low measure of the grass consumed. In an earlier experiment (**Expt. 2**), 10 *Eisenia fetida* had been found to consume 17.6mg wet weight /worm/day for 98 days, using spoil as a substrate. Again as cylinders were used, spoil might have contaminated grass for the second weighing.

These results compare well with Edwards and Bohlen (1996). They quote Franz and Leitenberger (1948), who recorded 20.4mg/day of hazel litter for *Lumbricus terrestris*, and Haimi and Huhta (1990), who recorded 19mg/g wet weight of earthworms/day for *Lumbricus rubellus* and 26mg/g wet weight for *Dendrobaena octaedra*. Among other examples these figures are typical, but all records are of fresh weight. In this work the grass mowings had been allowed to become limp before being used and dried. Water content in fresh grass would be about 90%. (Galston 1972.)

8.2.1. An investigation into an alternative feed (Expt. 8).

It had been noticed that in experimental cultures of worms using wilted grass, there had been a tendency for the grass to dry out further and become unpalatable to the worms. (It had been necessary to allow the grass to wilt before use to reduce the possibility of fermentation taking place, and the resulting rise in temperature harming the worms.) Cylinders containing sand and spoil both needed water adding occasionally to prevent drying out.

8.2.2. Method.

The experiments using the larger perspex cylinders were repeated using an excess of vegetable matter, (kitchen waste), to provide more liquid. The mass of 10 worms in each cylinder was 2.5g (approx.)

8.2.3. Results.

After six weeks the vegetable waste appeared to be more nutritious for the worms than the grass. There were signs of a great deal of activity in the cylinders. The spoil was well worked and crumbly in texture, and there was a lot of vegetable tissue mixed in with the spoil in all four cylinders. In two of the cylinders, potato peel which had been part of the kitchen waste had begun to sprout with roots going well into the spoil. On investigating the contents of one of the cylinders seven worms were found which together weighed 2.4 g. See **Table xix**, and **Plate XIX**, **Page 122**.

Table xix, mixed feed.		
	No of worms	Mean weight (g)
Start	10	0.25
10 weeks	7	0.38

8.2.4. Conclusions.

These seven survivors had a mean mass greater than that when originally placed in the experimental situation.

Photographs were taken, and the cylinder was set up again with fresh feed. The other three were not disturbed at this point.

8.3.1. Trials with a high water content feed. (Expt. 9.)

In order to test an alternative food source with an even higher water content than wilted grass, a further trial was carried out.

8.3.2. Method.

Four polythene bags were set up with four *Eisenia fetida* in each, with sand and chopped courgette. A second set of 4 bags was set up with spoil replacing the sand.

The bags were placed in a dark cupboard and left untouched for 34 weeks.



Plate XIX. Result of *Eisenia fetida* working in spoil in large cylinder.
Note the potato plant, centre.

8.3.3. Results.

The courgette had collapsed completely producing a wet mud with both sand and spoil, so that conditions were much wetter than in the cylinders of sand, (or spoil,) with wilted grass. Worms were still alive in some of the bags, see **Table xx.**

Table xx. Worms in a food source with a high water content.						
medium	no.	init wt(g)	mean(g)	final no	final weight(g)	mean (g)
sand	4	1.52	0.38	3	1.27	0.42
"	4	1.48	0.37	2	0.87	0.43
"	4	1.67	0.42	0	0	0
"	4	1.55	0.39	1	0.63	0.63
spoil	4	1.44	0.36	1	0.53	0.53
"	4	1.54	0.38	0	0	0
"	4	1.30	0.32	4	1.34	0.33
"	4	1.61	0.40	2	0.76	0.38
Initial pH of spoil 3.5, final pH of spoil 5.2.						

8.3.4. Discussion.

Survival rates varied from 0 to 100%, with the mean survival in sand being 37.5%, and in spoil being 43.75. No breeding had taken place, but the survivors appeared healthy. These results suggest that a plentiful supply of water is helpful to the survival of *Eisenia fetida* to prevent dessication of the worms and their habitat.

8.4.1. The effect of liming spoil on worm populations (Expt.10).

Because the pH of the spoil was low, it might be possible to improve the final rise in pH caused by earthworms if lime is added before worms are introduced.

8.4.2. Method.

For the purposes of this experiment, four large perspex cylinders were used. Spoil from the surface of a bare patch of the tip (see soil studies) was placed in the cylinders. Examination of this area had shown that no worms were present, and pH tests showed that the spoil was very acid. As deduced from the soil studies, the presence of pyrite in the shale led to a lowering of the pH on oxidation, and this acidity was hostile for worms.

The pH recorded was 3.5 at the surface and that is the lowest limit for *Lumbricus rubellus* and *Octolasion cyaneum* (Sims and Gerard 1985). Other species have higher minima of pH, *Eisenia fetida* has a lowest limit of 4.3.

Four treatments of spoil with horticultural lime were made. The recommended treatment of soil with lime (55% CaO equivalent), is 200gm/m², (2 tonnes / hectare), or in the case of heavy clay 400gm/m². (Vitax 1997). These two rates were adopted plus two further doublings of the rate as the spoil is weathered to a fine clay and has additional sources of acid.

The application rate on each cylinder (g) was as follows:

3.125, 6.25, 12.5, 25.0

These amounts of lime were added to the cylinders and lightly raked in. Mixed kitchen waste (vegetable peelings etc.), was placed on top as a food source. 250 ml of water was then poured onto the top of each cylinder to ensure that sufficient moisture was present for the worms, and for the lime to be washed into the spoil.

On the following day after the spoil had become settled, 10 *Eisenia fetida* were placed on top of the kitchen waste in each cylinder.

A photograph was taken to record the nature of the spoil after being worked by worms for thirty weeks.

8.4.3. Results.

Evidently some worms had escaped from these cylinders, as several dried remains were found on the floor nearby. Loss was not attributed to the cold as these cylinders were much larger than the other ones. See **Table xxi**, and **Plate XX, Page 126**.

Table xxi. Lime addition to spoil.

Initial no. worms	Equivalent lime rate T/hectare	final pH	Worms surviving	Weight worms(g)
10	2	5.1	2	0.78 (mean 0.39)
10	4	5.3	0	0
10	8	5.5	2	0.54 (mean 0.27)
10	16	5.6	4	0.93 (mean 0.26)

8.4.4. Discussion.

These worm sizes are typical of healthy mature *Eisenia fetida*. The rise in pH was not as great as might have been anticipated. Similar increases have been achieved without the use of lime, perhaps the rise in pH would be more permanent than that gained by using worms alone on spoil. The final pH correlates with the lime application rate, and might suggest there was little influence by the worms. However, examination of the worked spoil as seen in the photograph shows that the spoil was texturally altered.

These results suggest that the availability of water from plant remains is a major factor in the survival of *Eisenia fetida*, as losses in this experiment were attributed to



Plate XX. Result of *Eisenia fetida* working spoil with lime.
Note the finer texture of the spoil.

escapes. In a compost heap the vegetation will provide a great deal of moisture from cell sap, and provided these conditions are repeated under laboratory conditions or in the field, then *Eisenia fetida* will survive and breed.

8.5. Overall Conclusions for experiments.

These experiments suggest that *Eisenia fetida* can ameliorate acidic colliery spoil. An improvement of spoil texture from solid clay to an open crumb structure was noted especially in experiments 3, 8, and 10. pH change reducing the acid levels were found in experiments 3, 6, and 9. In the presence of spoil *Eisenia fetida* was shown to feed at normal rates in experiments 2 and 7, and found to be able to breed in experiments 4 and 5. These results indicate that further investigation into the use of *Eisenia fetida* in the amelioration of colliery spoil is worthy of consideration.

Chapter 9.**Summary and discussion.****9.1.1. The tip at Brodsworth.**

The ecology of the tip under investigation has been studied, and it shows many similarities with those examined by other researchers, both in regard to spoil and vegetation growing on the main part.

Sufficient history, from map studies chiefly, has been found to indicate that the contrasting vegetation at the west end of the tip is probably due to local soil, rich in Magnesian Limestone, being dumped there at the building of the A1(M), trunk road. Historical studies also indicate that the tip material consists mainly of rocks produced by sinking the shaft, together with waste produced during the first few years of production only. Tipping on the site probably ceased by 1920 or shortly after that date and the tip was shortened by the intrusion of the A1(M).

Soil studies indicate that the rocks, mainly shales, have weathered on the surface to clays. These clays are not rich in plant nutrients, and due to the presence of oxidising Pyrite, have low pH.

Studies of the spoil and plant life on Brodsworth tip indicate that there is slow succession taking place. Over the greater part of the tip, *Betula sp.* were dominant, and associated species typical of coal measures vegetation are present. There was successful colonisation of local plant species, including calcicoles, at the west end of the tip where it appears that topsoil had been added. However on other local sites, topsoil was eroding, so that topsoiling is not a universal panacea.

Several areas of the tip are devoid of vascular plants. These areas had lower pH than the vegetated parts.

The limited earthworm species present are found only in the vegetated parts of the spoil, while none are found in the bare spoil. There is no conclusive evidence to show differences between earthworms present in the spoil and those found at the west end.

It appeared that it was possible to relate worm populations to migration across the site, *Lumbricus rubellus* and *Lumbricus festivus* were found with the occasional *Lumbricus terrestris*. The steepness of the west slope prevented accurate worm counts so it was not possible to relate the higher soil pH to worm numbers, contrasting with the flatter, more acid parts.

9.1.2. The problems associated with introducing earthworms.

Should any worms be introduced at the surface of the spoil heap, they would be faced with an environment which would not be favourable for their establishing a stable community. Any species of worm which cannot tolerate some level of acidity will not be at all suitable. Even worms which can cope with some acidity will quickly encounter a hostile environment on going more than a few millimetres below the surface.

One earthworm which is often found to be present in old spoil heaps which have a covering of birch is *Lumbricus rubellus*, (as at Brodsworth). This is a surface dwelling worm, which is able to gain nourishment from the litter layer and does not penetrate deep into the mineral layer, if at all. *Lumbricus rubellus* can tolerate pH 3.7 (Satchell 1955).

Lumbricus terrestris is a deep burrowing worm which is favoured by some researchers because of its ability to take large quantities of plant matter below the surface. 5 tons/ha of leaf litter in a 2 year period was reported by Vimmerstedt and Finney (1973), on coal strip mine banks in Ohio. However a pH of 6.2 - 10.0 is preferred, (Sims & Gerard 1985), so before introducing such a worm to a spoil

heap, some amelioration of the pH should already have taken place. Also the reproduction rate, typical of a 'K' strategist is low. It would appear that making use of the deep burrowing by *Lumbricus terrestris* might be better left until amelioration of the surface has already been achieved by other species.

Satchell (1955) however, suggests that *Lumbricus terrestris* can survive pH 3.7 (see Fig. 2). Also Vimmerstedt (1983), successfully introduced *Lumbricus terrestris* to revegetated mine spoil, pH 3.5, which might suggest that provided a suitable food source is present then low pH will be tolerated.

Aporrectodea longa, having a pH range of 6.7 - 9.4 would have difficulty in penetrating far below the surface. It could however, be important as a worm which habitually casts, thus turning the soil over.

Octolasion cyaneum has been found on and around colliery spoil, including Brodsworth, but is sluggish. It prefers a moist habitat and can tolerate a wide range of pH, from 3.5 to 8.2 (Sims & Gerard 1985). The same source also reports that this worm, though common, is never abundant. *Octolasion cyaneum* reproduces parthenogenetically, and this, coupled with its tolerance of a wide range of pH might recommend its use in spoil reclamation, but some means would have to be found to increase its reproduction rate so that numbers would be large enough to have some impact on the condition of the spoil.

Eisenia fetida is normally found in compost heaps, and in conditions of similar high organic composition. This worm reproduces at a rapid rate when conditions are favourable, ie a substrate composed chiefly of decomposing organic matter. Note that the organic matter should not be completely decomposed, as *Eisenia fetida* shows a marked preference for reasonably fresh plant waste. (Frederickson *et al* 1997).

9.2.1. Experimental work.

Experience with use of *Eisenia fetida* in composting certainly supports this view. Given a depth of kitchen waste this worm can continue in the coldest of winter temperatures working the waste. Experiments have also shown that *Eisenia fetida* will enter weathered colliery spoil and add plant material if it is loosened and not compacted.

The worm cultures have demonstrated that *Eisenia fetida* is able to ameliorate colliery spoil in respect of texture and pH. *Eisenia fetida* has also been shown to be able to breed in colliery spoil provided an ample supply of food material is available and the moisture levels are kept high. Kitchen waste or surplus fruit or vegetable waste as from food preparation units would provide a substrate for the worms. The weathered spoil being of a clay nature would not readily drain the fluid. Thus the substrate would remain very moist for long periods while allowing the ammonia in the water to permeate slowly into the spoil. Trees subsequently planted on the site would have a neutral soil to root into as well as having added nutrients present. When a more neutral soil is achieved then *Lumbricus terrestris* can be introduced to deepen the extent of drainage and enable deeper root penetration by the trees. By this means a true soil could be formed which relates to the subsoil and "parent" rock underneath.

While a number of different approaches to possible methods of ameliorating colliery spoil have been made in this study, it must be conceded that no large number of repetitions have been made. However in all trials with well nourished *Eisenia fetida* in weathered spoil, the texture of the substrate has been loosened from a compacted clay, and the pH has been raised.

9.3.1. Possible sources of organic material.

Although grass mowings have been used in the cylinder experiments with success, and kitchen waste provides nutrients for *Eisenia fetida* in a compost bin,

the use of other man made litter would have a more direct influence on reducing pollution problems. There are many pollutants which might be used to provide nutrient for worms as well as improving the texture of colliery spoil. Two examples quickly spring to mind:

30m tonnes of sewage sludge (Davis, 1987) and,

120m tonnes of farm manures are produced annually in Britain. (Gray & Williams 1971).

The use of *Eisenia fetida* on such wastes in association with colliery spoil is envisaged as addressing two problems at once.

Sewage sludge includes phosphate rich detergent waste which has had damaging effects on waterways (Mellanby 1972). The lack of phosphate in colliery spoil has been examined earlier (see Soil Analyses, chapter 4), and the addition of a phosphorus-rich sludge would help redress the balance of nutrients in the spoil heap. Additional phosphate would encourage root formation thus speeding up plant establishment and growth rate.

Eisenia fetida has been used to break down pig slurry at Rothamsted (Edwards 1988), where the surplus worms have then been returned to pigs as a protein rich feed (Sims and Gerard op cit). To use *Eisenia fetida* as a means of combining colliery spoil with organic waste would suggest itself as an ideal method of building an effective clay humus complex in the spoil (see Chapter 4).

9.3.2. Optimum conditions.

The optimum conditions for breeding *Eisenia fetida*, according to Edwards (Op cit), would be in an aerated organic waste with the following conditions:

- | | |
|----------------------------|------------------|
| 1. Worm / waste mass ratio | 1/10 |
| 2. Moisture content | 80 - 85% |
| 3. Temperature | 25°C (15 - 25°C) |
| 4. pH | 5.0 |

These conditions should be aimed for in a reclamation programme. In the field such conditions, even if set up at optimum, would not be maintained for long. However, conditions close to the optimum could be maintained if preparations were made with care.

The moisture content needs carefully monitoring, it has been found that dry conditions must be avoided if worms are to survive. If the moisture content of the starting medium is close to 80 - 85%, be it grass mowings, potato peelings or whatever vegetable waste, the clay nature of the weathered spoil will prevent rapid drainage of moisture from the waste. If the waste is laid in trenches and covered over then evaporation will be slowed.

Experience has shown that spoil heaps can dry out in periods of drought, and in summer months a cover of spoil would reduce water loss to the atmosphere. Should the trench become flooded in wet weather, then earthworms can withstand a period of submersion. As the waste would not be packed tightly to assist aeration, then the upper parts of the waste will drain readily.

A pH range 4.3 - 7.5 (Sims and Gerard, Op cit), is tolerated by *Eisenia fetida*. Low pH levels are expected in vegetable matter (Mason 1976), and pH 3.0 - 3.5 can be expected in an unvegetated but weathered spoil. (Soil analyses results). It has been shown that the pH of colliery spoil can be raised by *Eisenia fetida* working in plant material on colliery spoil (see Chapter 5). It has also been shown that a vermiculture bin can produce pH 7.0. It has been assumed that this raising of pH is due to the production of ammonia. Certainly *Eisenia fetida* prefers to avoid, if possible, worked vegetable matter where ammonia will be present. Normally the worms will work upwards in an undisturbed compost heap as fresh waste is added.

9.4.1. Possible further study.

Amelioration attributed to earthworms in colliery spoil has been noted in texture and pH only. Should similar work be repeated, then chemical analyses on the worked spoil might be appropriate to ascertain if the soil chemistry has been altered.

9.4.2. Field trials.

When this situation is translated to the field, it is anticipated that the breeding will take place in the pure vegetable matter, with surplus ammonia being readily dissolved in the liquid waste produced and being absorbed by the spoil. This process should reduce any problems of ammonia toxicity. By this means the pH of the spoil below the trench should also be raised, as well as the plant nutrients added. This situation will be more conducive to the establishment of tree roots, than waiting perhaps 100 years (Hall 1957), for natural vegetation establishment to take place.

As suggested above the possibility of attempting to reproduce the indoor experiment in a series of field trials is envisaged. It is hoped to carry out field trials at the 'Earth Centre' situated on the former Cadeby Colliery site in South Yorkshire. (GR SE525001.)

Four types of plot are required each measuring 5 x 4 metres. These are to be prepared as follows

1. Ploughed only. (Control.)
2. Ploughed and harrowed only.
3. Ploughed, organic addition made, and harrowed.
4. Ploughed, and organic addition made in the trenches.

Inoculation with prepared earthworm inoculation units containing colonies of *Eisenia fetida*, initially.

Notes.

Plough depth to be 20cm.

The total number of sample plots will be governed by the practicality of this work being carried out, and in particular the practicality of investigating large numbers of plots to measure the population size after 10 months.

The nature of the organic addition will depend on availability and practicality of various materials. eg Dried sewage sludge may be available but its use on such a project may be prohibited, if it is considered to be too close to a watercourse.

Should the initial inoculation prove successful then a second inoculation of *Lumbricus terrestris* would be made in order that the spoil might be worked more deeply.

Appendix 1.

The history of the tip at the site of Brodsworth Colliery was described briefly in the main text. The maps on which this history was based are illustrated here and can be used to trace the development of the site in relation to the construction of the first tip, the railway, and the nearby motorway.

- 1854. The outline of Pickburn, Long Lands Lane, and Red House Lane are little changed from the Inclosures map. Field boundaries are similar to the 1815 map in the main text. Two Limestone quarries are shown and Underhills Drain is marked.
- 1930. The railway dominates this map but the shape of Red House Lane is easily recognised as is a nearby field boundary. The original tip is seen in the centre with a tub rail going up. Underhills Drain has been diverted.
- 1956. Although less detailed than the 1930 map, this map shows two new aerial bucket systems, which were used in conjunction with deeper workings, and led to the later tip now grazed by sheep. If this map is compared with the 1966 map in the main text, the intrusion of the motorway on to the site can be appreciated.

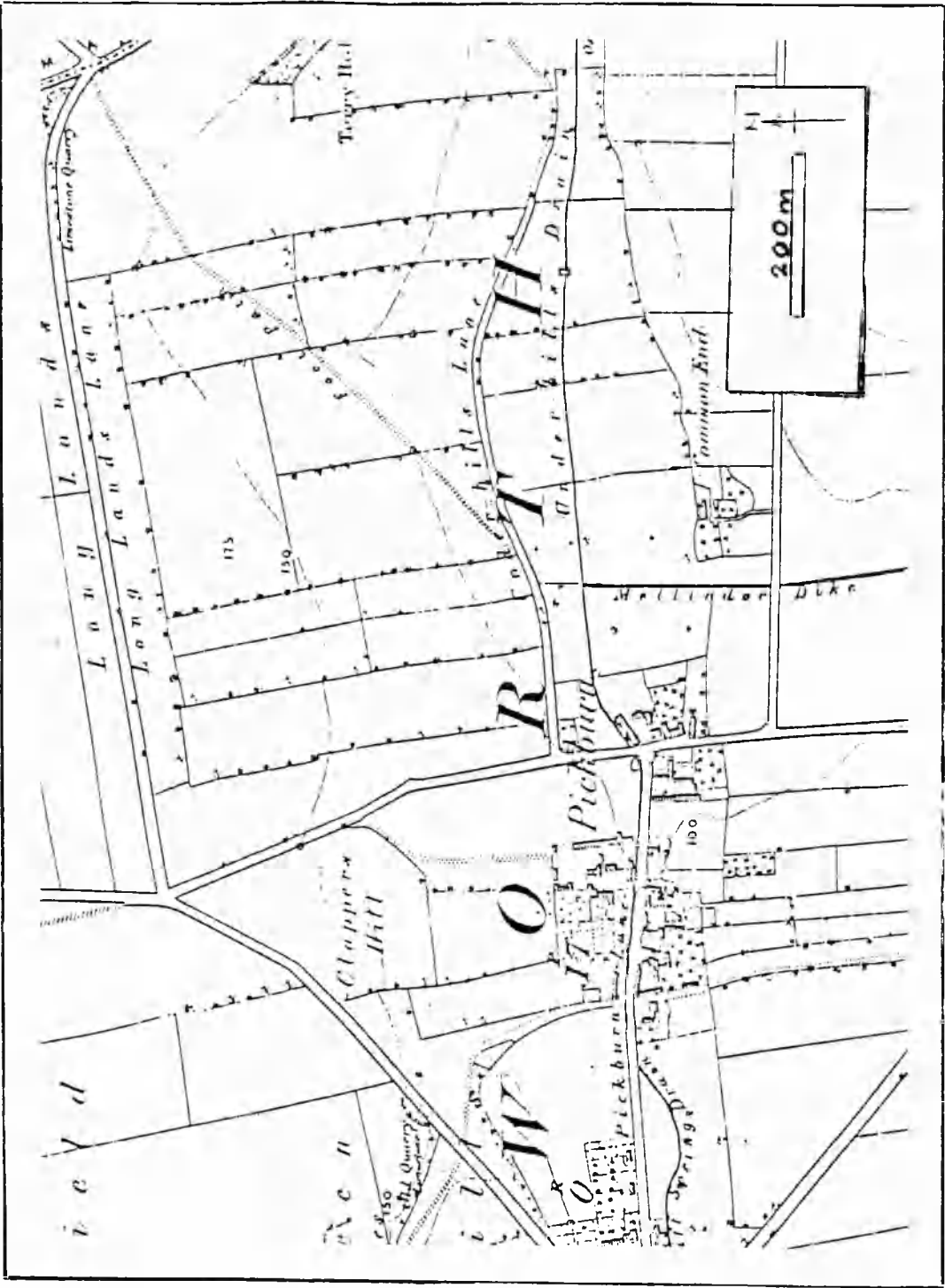


Fig. 19. OS map 1854.
Road layout can be traced today.

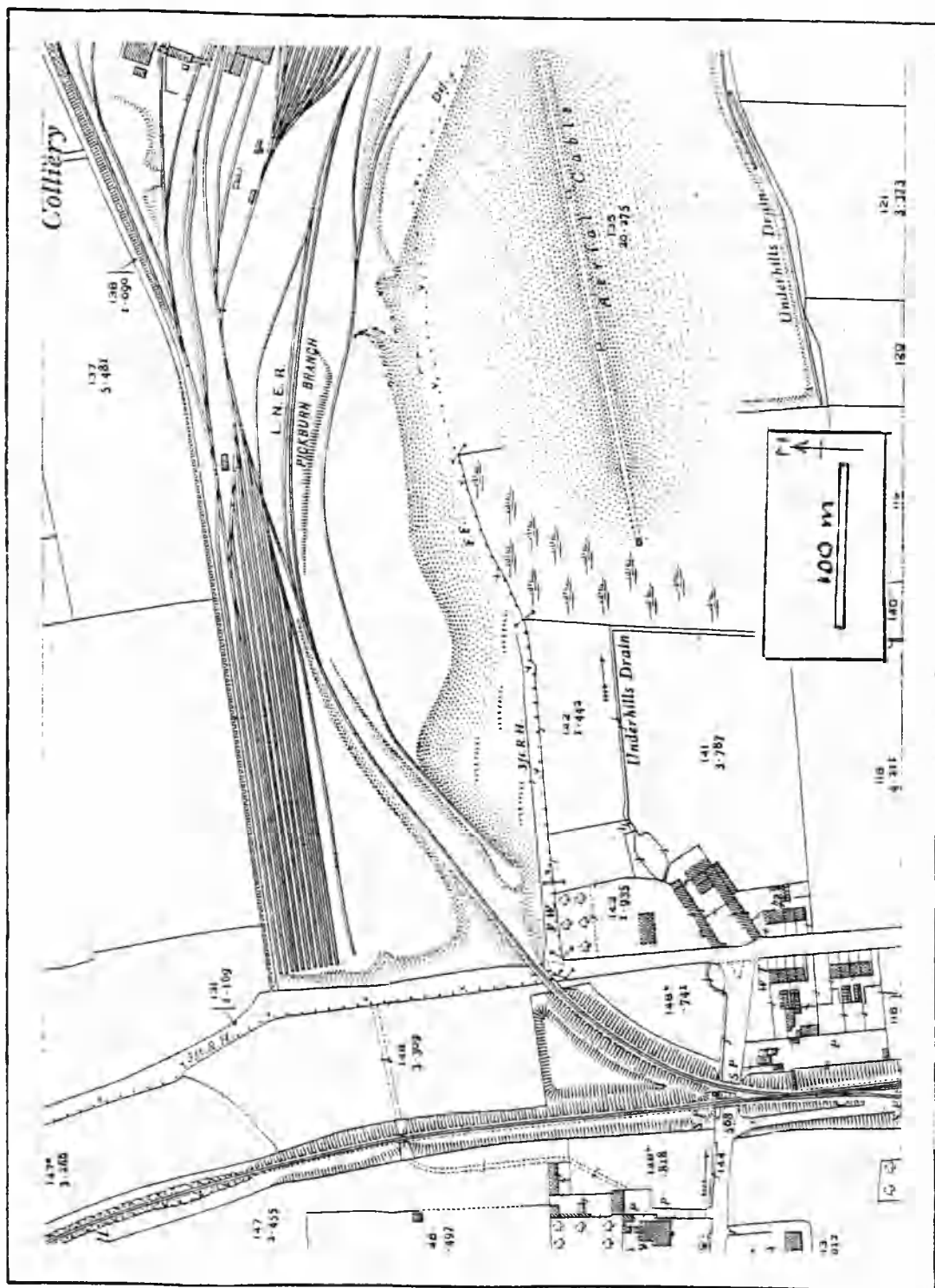


Fig. 20.

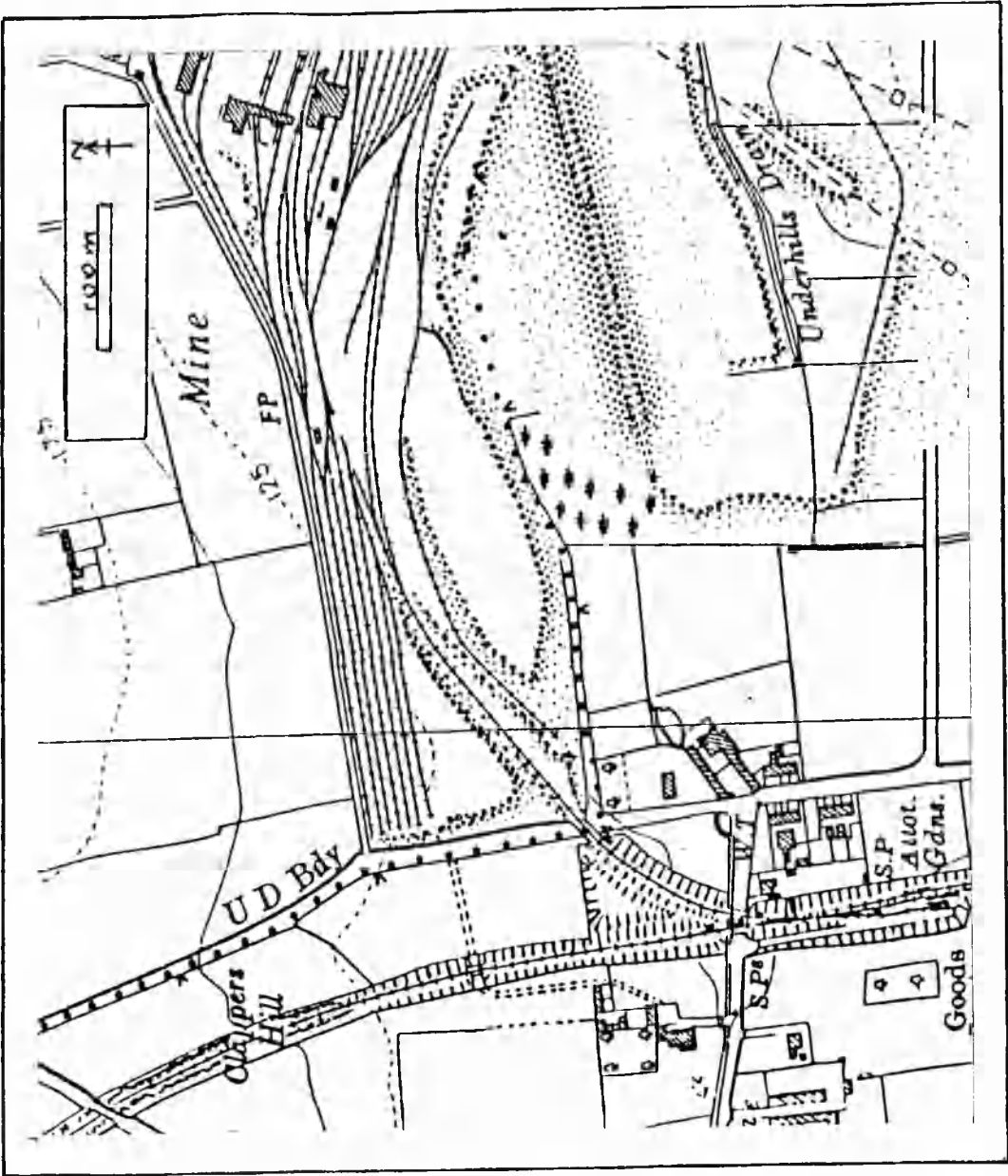


Fig. 21. OS map 1956.

Appendix 2.**Plant species found at Brodsworth tip.**

(Plant names based on Fitter et al. 1974)

On the main part of the tip.Trees

<i>Betula pendula</i>	Silver Birch	dominant
<i>Betula x</i>	Birch hybrids	
<i>Crataegus monogyna</i>	Hawthorn (seedlings)	common in parts
<i>Prunus avium</i>	Wild cherry	
<i>Quercus robur</i>	Common Oak (seedlings)	
<i>Salix cinerea</i>	Grey Willow	

Shrubs

<i>Lonicera periclymenum</i>	Honeysuckle
<i>Ligustrum vulgare</i>	Wild Privet
<i>Ribes sp</i>	Flowering Currant
<i>Rosa canina agg.</i>	Dog Rose
<i>Rubus fruticosus agg.</i>	Bramble

Herbs

<i>Borago officinalis</i>	Borage
<i>Carlina vulgaris</i>	Carlina Thistle
<i>Digitalis purpurea</i>	Foxglove
<i>Epilobium angustifolium</i>	Rosebay willowherb
<i>Heracleum sphondylium</i>	Hogweed
<i>Hieracium sp</i>	Hawkweed
<i>Galium aparine</i>	Cleavers
<i>Inula conyza</i>	Ploughman's Spikenard

<i>Senecio jacobaea</i>	Ragwort
<i>Taraxacum officinale agg</i>	Dandelion
<i>Tussilago farfara</i>	Coltsfoot

At the western end. (made up part) of the tip.

Trees

<i>Acer pseudoplatanus</i>	Sycamore
<i>Crataegus monogyna</i>	Hawthorn
<i>Fraxinus excelsior</i>	Common Ash

Shrubs

<i>Glechoma hederacea</i>	Ground Ivy
<i>Prunus spinosa</i>	Blackthorn

Herbs (C = calcicole.)

<i>Agrimonia eupatoria</i>	C	Agrimony
<i>Achillea millefolium</i>		Yarrow
<i>Anemone ranunculoides</i>		Yellow Anemone
<i>Ajuga reptans</i>		Bugle
<i>Bellis perennis</i>		Daisy
<i>Centaurea nigra</i>		Black Knapweed
<i>Centaurea scabiosa</i>	C	Greater Knapweed
<i>Centaureum erythraea</i>	C	Common Centaury
<i>Cerastium fontanum</i>		Common Mouse Ear
<i>Dipsacus fullonum</i>		Teasel
<i>Fragaria vesca</i>		Wild Strawberry
<i>Hypericum hirsutum</i>	C	St John's Wort
<i>Heracleum sphondylium</i>		Hogweed
<i>Hypochaeris radicata</i>		Common Catsear

<i>Inula conyza</i>	C	Ploughman's Spikenard
<i>Leontodon sp</i>		Hawkbit
<i>Leucanthemum vulgare</i>		Ox Eye Daisy
<i>Lotus corniculatus</i>		Birdsfoot Trefoil
<i>Medicago lupulina</i>		Black Medick
<i>Ophrys apifera</i>	C	Bee Orchid
<i>Pilosella officinalis</i>		Mouse Ear Hawkweed
<i>Pimpinella saxifraga</i>	C	Burnet Saxifrage
<i>Plantago lanceolata</i>		Ribwort Plantain
<i>Primula veris</i>	C	Cowslip
<i>Ranunculus acris</i>		Meadow Buttercup
<i>Ranunculus ficaria</i>		Lesser Celandine
<i>Rhinanthus minor</i>		Yellow Rattle
<i>Rumex acetosella</i>		Sheep's Sorrel
<i>Senecio squalidus</i>		Oxford Ragwort
<i>Senecio vulgaris</i>		Groundsel
<i>Stellaria media</i>		Common Chickweed
<i>Trifolium repens</i>		White Clover
<i>Trifolium pratense</i>		Purple Clover
<i>Tragopogon pratensis agg</i>		Goatsbeard
<i>Veronica chamaedrys</i>		Germander Speedwell
<i>Vicia cracca</i>		Tufted Vetch

Grasses

<i>Arrhenatherum elatius</i>	False Oat-grass
<i>Agrostis stolonifera</i>	Creeping Bent
<i>Dactylis glomerata</i>	Cocksfoot
<i>Deschampsia flexuosa</i>	Wavy Hair-grass
<i>Festuca spp.</i>	Fescue
<i>Holcus lanatus</i>	Yorkshire Fog

Poa pratensis

Smooth Meadow Grass

To the north side on the site of the former railway siding.

This site is largely covered by sapling birch and associated plants as on the tip. There are in addition, some notable plants including the following.

<i>Salix caprea</i>	Goat willow
<i>Salix cinerea</i>	Grey willow
<i>Epilobium parviflorum</i>	Hoary willowherb
<i>Ranunculus repens</i>	Creeping buttercup
<i>Tripleurospermum inodorum</i>	Scentless mayweed

In a few small marshy places.

<i>Carex sp.</i>	Sedge
<i>Phragmites australis</i>	Reed
<i>Typha latifolia</i>	Great Reedmace
<i>Juncus inflexus.</i>	Hard Rush

Three or four separate groups of.

<i>Ophrys apifera</i>	Bee orchid
<i>Malus sp</i>	Apple (single specimen)

Many fungi, including:

<i>Lycoperdon sp</i>	Puff ball
	Bracket fungus
<i>Amanita muscaria</i>	Fly agaric

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